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UNEP/DEIA/TR.97-1
RIVM/402001007

The Future of the Global Environment: A Model-based Analysis Supporting UNEP's First Global Environment Outlook

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UNEP

United Nations Environment Programme

Units, conversion factors and symbols

kilo (k)	10^3
Mega (M)	10^6 = million
Giga (G)	10^9 = billion
Tera (T)	10^{12} = trillion
Peta (P)	10^{15}
Exa (E)	10^{18}
ton	metric ton = 1000 kg
Mton	million ton = 10^{12} g = Tg
1 ha	10,000 m^2
J	Joule
cal	calorie = 4.2 J
ppmv	parts per million by volume
N	Nitrogen
P	Phosphorus
S	Sulpur
C	Carbon
CO_2	Carbon dioxide
SO_2	Sulphur dioxide
NO_x	Nitrogen oxides
GDP	Gross Domestic Product
GNP	Gross National Product
GWP	Gross World Product

ISBN: 92-807-1633-6

For bibliographic and reference purposes this publication should be referred to as:

RIVM/UNEP (1997). Bakkes, J.A. and J.W. van Woerden (eds.). The Future of the Global Environment: A model-based Analysis Supporting UNEP's First Global Environment Outlook. RIVM 402001007 and UNEP/DEIA/TR.97-1

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PREFACE

Integrated assessment is one of the more powerful information tools to rational environmental policy. Integrated assessment distills practical messages for policy from available, but often fragmented scientific understanding and data. It is ‘integrated’ because of the linkages between the different environmental problems themselves and between the forces that drive those problems and the options available for our responses. Moreover, integrated assessment aims at providing a - be it crude - look at the whole, rather than a detailed picture of those issues we understand best.

Integrated assessments in support of environmental policy have already been applied to a number of countries and regions, and to international negotiations. UNEP's first Global Environment Outlook (GEO-1) can be seen as a step towards making the tool of integrated assessment more widely available as a means for focusing action.

The technical report before you documents RIVM's contribution to UNEP's first Global Environment Outlook report. The RIVM contribution focuses on one particular element of integrated assessment: looking ahead (Chapter 4 in GEO-1).

Current patterns in production and consumption typically manifest their environmental and resource consequences only after important delays. This is because many environmental and resource processes are slow and cumulative. Also in the whole process of taking remedial action there are considerable inherent delays. As is illustrated by this report, a ‘what if’ analysis helps us to look beyond the delays as well as we can. In policy preparation, ‘what if’ analysis buys time so as to consider options and take preventive action. And obviously, the earlier action is taken, the more cost-effective it is. And, equally important, contemporary modelling makes regional differences part and parcel of such an analysis.

A draft version of the present report was reviewed by individual scientists between April and August 1996. Extensive comments on the report were also received in policy-oriented consultations in all six UNEP regions. Besides contributing significantly to the end result, both rounds of comments were of key importance in extracting the messages from the present analysis for GEO-1. The comments also guided the revision of the April draft leading to the present report. One particular revision has been the addition of a brief reconnaissance in Chapter 7 on the potential impact of enhanced policies world-wide. An account of the regional consultations held on the entire draft Global Environment Outlook will be published separately in this series.

This report illustrates that integrated assessment and modelling techniques can be excellent tools for environment and development policy-setting. The methodology, however, will need to be further developed and adapted to the realities and expectations of diverse regions, incorporating alternative policy strategies and development scenarios. The GEO Working Groups dealing with models and scenarios will also need to expand the scope of the analysis to address social and - eventually - institutional issues. Furthermore, environmental quality issues, such as pollution, need more attention in comparison to quantity issues only. Data, scale and uncertainty analysis will need to be improved.

However, we believe it justifiable to provide this contribution on a limited but timely basis as a start in the GEO process. The emerging network of collaborating centres for integrated assessment in all regions will be the starting point for broadening the base, both for consecutive GEO reports and for applications of integrated model-based analysis in support of regional, national or local policy issues.

We sincerely hope to receive many more comments on this report to guide the GEO process.

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ACKNOWLEDGEMENTS

Various sections and aspects of this report represent the work of different RIVM staff members:

Chapter 1 (methodology): Rob Swart with inputs by Jan Rotmans (currently with DPCSD)
Chapter 2 (the scenario): Rob Swart with inputs by Bert de Vries
Chapter 3 (interactions between land, water and the atmosphere): Joseph Alcamo (at present with the Center for Environmental Systems Research, University of Kassel); acidification by Jean-Paul Hettelingh; response options by Rob Swart
Chapter 4 (use of land and water): Gert Jan van den Born, with modelling of fresh water demand and availability by Olivier Klepper
Chapter 5 (nature and its diversity): Ben ten Brink
Chapter 6 (effects on human health): Louis Niessen, building on the work of Pieter Bol
Chapter 7 (responses): Marcel Berk, building on work by Rob Swart and inputs by Fred Langeweg
Appendices: Jaap van Woerden
Overall structure: Fred Langeweg
Project management: Jan Bakkes and Bert-Jan Heij, with Marcel Berk as project secretary.

Editors: Jan Bakkes (substantive editing) and Jaap van Woerden.

Data aspects and input-output processing were coordinated by Jaap van Woerden, who, with Jos Diederiks, Kees Klein Goldewijk and Raymond de Niet, acquired and processed most of the data. Eric Kreileman performed the calculations with the IMAGE model.

This report was enhanced by comments from many individual experts and organizations. Moreover, consultations in all UNEP regions during the summer of 1996 provided valuable comments. The reports of these consultations will appear as a separate background report to GEO-1.

Layout: RIVM's Studio, with the special assistance of Martin Middelburg. Marc van Leeuwen assisted with manuscript preparation. English language editing: Ruth de Wijs-Christensen and Michael Gould (Michael Gould Associates).

LIST OF REVIEWERS

The following list comprises people who participated in a review of a draft of this report and provided us with many useful comments and suggestions. We tried to incorporate these in the final version as much as possible. However, due to limitations of time, space and divergence in views on some issues not all comments and suggestions have been taken into account. Nevertheless, the present report did much benefit from the various suggestions made by:

Prof. Robert Ayres, INSEAD, France
Dr. Dirk Bryant, World Resources Institute, USA
Mr. Munyaradzi Chenje, on behalf of Environmental Resource Centre for Southern Africa/IMERCSA, Zimbabwe
Mr. Clement Dorm-Adzobu, together with other reviewers from the Network on Environment and Sustainable Development Africa (NESDA), Ivory Coast
Dr. James Edmonds, Pacific Northwest National Laboratory, USA
Prof. Genady Golubev, together with other reviewers at Moscow State University, Russia
Dr. Gilberto Gallopin, CIAT, Colombia
Prof. Lekan Oyebande, University of Lagos, Nigeria
Prof. Tony McMichael, London School of Hygiene and Tropical Medicine, United Kingdom
Prof. Ruben Mnatsakanian, Central European University, Hungary
Dr. Fred Muchena, ETC-Kenya, Kenya
Mr. Francis Ng, Center for International Forestry Research (CIFOR), Indonesia
Dr. Shuzo Nishioka, National Institute for Environmental Studies, Japan
Mr. Dennis O'Farrell, Environment Canada, Canada
Prof. Jyoti Parikh, Indira Gandhi Institute of Development Research, India
Dr. R K. Pachauri, Tata Energy Research Institute (TERI), India
Dr. Dhira Phantumvanit, together with other reviewers at the Thailand Environmental Institute (TEI), Thailand
Prof. Jan Rotmans, United Nations/DPCSD, USA
Dr. George Davis together with other reviewers at the National Botanical Institute, South Africa
Dr. Kamal A. Sabet, together with other reviewers at the Centre for Environment and Development for the Arab Region and Europe (CEDARE), Egypt
Mr. Richard Tol, Institute for Environmental Studies, The Netherlands
Mr. Keimpe Wieringa, European Environmental Agency
Dr. Zhang Shigang, together with other reviewers coordinated by the National Environmental Protection Agency, China
Dr. Veerle Vandeweerd, together with other staff of UNEP

KEY FINDINGS

Inequality increases in a wealthier and healthier world
In the Conventional Development scenario analyzed in this report, global per capita income increases by 50% and 100%, and life expectancy by 5% and 8%, by 2015 and 2050, respectively. However, inequalities in income between regions become larger in the scenario up to 2015, after which the gap begins to narrow. In some of the poorest regions the demographic transition stagnates and health problems persist.

Environmental pressures build up
Growth in consumption and production exceeds gains from improvements in productivity. In the scenario, energy efficiency is projected to increase by a factor of 1.2 by 2015 and 1.8 by 2050. At the same time, total demand for energy increases by a factor of 1.8 by 2015 and 2.6 by 2050. Agricultural efficiency is projected to increase by a factor of 1.2 by 2015 and 1.4 by 2050. At the same time, total food demand increases by a factor of 1.5 by 2015 and 2.0 by 2050. However, the regional differences in environmental pressures are great.

Renewable resources at risk of depletion
While depletion of exhaustible resources in the seventies was considered as a major threat to development, integrated assessment based on the Conventional Development scenario suggests that the degradation of renewable resources such as water, land and forests now creates risks that are much more urgent. This may increasingly hinder development on local and regional scales. In the scenario, social and economic capital seems to increase globally, while natural capital is being depleted.

Climate goals are not being achieved
Interacting biogeochemical cycles are increasingly disturbed by human activities. For example, the current commitments of the Climate Convention are insufficient to stabilize atmospheric concentrations in the coming century. Emissions of greenhouse gases from developing regions, notably Asia, will grow rapidly, leading to a 50% increase in 1990 of global carbon dioxide emissions by 2015, and more than a doubling by 2050. Consequently, in addition to increased preventive efforts to control emissions, preparing for adaptation to projected climate impacts becomes urgent. This is particularly true for areas vulnerable to climate impacts in developing regions in low latitudes. Another example is acidification, becoming more important in developing regions with vulnerable soils and accelerating economic development.

Can a ‘second’ world be fed?
The key challenge for the world’s agricultural sector will be how to feed double the present population by 2050. Increasing demand for animal products will further boost total agricultural demands. Theoretically, increasing productivity, extending agricultural land and reversing land degradation can provide sufficient food on a global scale. Achieving this and ensuring the adequate distribution of food pose a formidable challenge. Regions such as Asia, West Asia and Africa are projected as being able to increase their food imports, enlarging the scale of agricultural trade significantly.

A serious threat to development by water scarcity confirmed
In many regions, water demand from industry and households is in increasing competition with water for agricultural production. Preliminary global analysis at the catchment level confirms that water scarcity is affecting increasingly large areas, particularly in West Asia and Africa. This may lead to serious security problems, conflicts and large-scale migration. Integrated water management at the riverbasin level and adequate water pricing form the key to alleviating these pressures.

Further conversion of natural lands appears inevitable
In the Conventional Development scenario, agricultural land increases from one-third to almost one-half of the earth's land mass by 2050. This increase is concentrated in tropical and subtropical zones. The remaining natural areas are formed to a large extent by mountainous, boreal, subpolar, arid and semi-arid lands, which are less suitable for human settlement. Simultaneously, these remaining natural areas will be under increasing pressure from population growth, economic development and associated environmental stresses such as climate change. Consequently, biodiversity will be severely affected in the scenario, both in terms of quantity and quality.

Environmental degradation may threaten global health in the long term
In the Conventional Development scenario, life expectancy increases worldwide, up to 70 years. Morbidity declines drastically, especially in developing countries. Expected improvements in income, education, nutrition and water supply will stimulate the decline in fertility needed to stabilize the global population, but how much and how fast is by no means certain. Unfortunately, in many areas (notably, Sub-saharan Africa and many urbanized areas) environment-related health problems will persist or be aggravated. Also, in the long term, an increased population, older in composition and more demanding, will further increase environmental pressures and is likely to undermine its own resource base, which may eventually threaten global health. In this context, increased environmental protection, especially in developing countries, will be essential in the prevention of an increase of disease.

Environmental transitions needed and, in some cases, already started
With current technology - where appropriately coupled to behaviourial changes - major progress can be made to reverse the negative developments outlined above and accelerate transitions towards the sustainable use of energy, raw materials, land and water. While the onset of these transitions can be discerned, adequate social, economic and institutional conditions have to be met for realizing these transitions in working towards the Agenda 21 goals.

Linking issues and boosting efficiency in a comprehensive approach
To promote transitions, linking of issues provides new options for joint gains by the different actors implicated. Many environmental problems can be addressed by focusing efforts on integrated energy and agriculture policies rather than on single-issue policies. Just to keep pressures at current levels, resource efficiencies would have to increase by a factor of 4 to 5 globally by 2050. To reduce pressures towards sustainable levels and re-allocate available resources more equitably, this factor on a regional level may have to be as high as 20.

Impact of enhanced policies would be large
Technically, there is much room for mitigating future increases in pollution, resource use and pressure on natural areas. That is: if best available technology could be applied to all new investments, the projected environmental impacts would be much less severe. More structural changes in production and consumption patterns - such as a shift to renewable energy resources and a change of diets - would give humankind even more space. Obviously, this will require broad access to capital and knowledge, and most of all it requires the political determination to make the world a sustainable one.

Integrated assessment: not a solution but a framework for analysis and debate.
The integrated assessment in this report is based on a quantitative systematic framework for analyzing future global and regional developments, and their interlinkages. However, this assessement is based on a limited set of methodologies and only one scenario depicting neither the most probable nor the most desirable future. To cover regional and disciplinary insights, as well as scientific uncertainties, more comprehensively than possible in this contribution to the first Global Environment Outlook and to focus more on communication between stakeholders and scientists, future analyses should make use of a wider set of methodologies, sensitivity analyses and scenarios.

1 SOCIAL AND ECONOMIC DEVELOPMENT AND PROTECTION OF ENVIRONMENTAL RESOURCES: THE CORE QUESTIONS AND HOW TO ADDRESS THEM

1.1 Key questions, methods, and definitions

Introduction and key questions

What kind of world will future generations inherit? Which of our present problems are likely to persist and what new problems can we expect to emerge, where and when? What are the main driving forces behind these problems, to what extent can they be solved and what will viable solutions cost? Does rapid economic growth and globalization exacerbate these problems, offer solutions, or perhaps do both at the same time? These are questions that the Global Environment Outlook process will address in order to identify emerging issues and support priority setting for international action. Chapter 2 of the Global Environment Outlook surveys regional priorities and current responses. The present contribution attempts to address the above questions by exploring the future in a structured fashion. The sheer complexity of the issues may well overwhelm decision-makers. One of the ways to simplify and structure the issues and their interactions is to apply modelling techniques and scenario analysis.

Focus and methods

The above questions are far-reaching because they examine issues — changes in conditions that affect human health, the depletion of natural resources, and a serious loss of biodiversity as a result of developments in other sectors — that will have a major impact on human lives. While there are many environmental changes and impacts associated with social and economic developments, this contribution to the first Global Environment Outlook is not primarily intended to deal with all of these. Rather, the intention is to demonstrate the advantages and feasibility of model-based assessment[1] applied to two important areas where environment and development interact, namely global cycles and the use of the earth's limited land resources[2]. Even with these limitations, this is no easy task. There are a number of factors which may influence the accuracy of the results of such an assessment: gaps in knowledge[3], related deficiencies in the structure of the models, and the fragmentary nature and, in some cases, limited reliability of available data. Nevertheless, the seriousness of the problems outlined in the other contributions to the Global Environment Outlook report makes it all the more urgent to start indicating and assessing systematically both current and future risks to the environment and to development.

[1] To analyze the real world it is necessary to assess the multiple and complex interactions between the environment and the socioeconomic fabric of life. This requires the integration of diverse sets of information derived from many different sources. Systems analysis models provide one set of tools that can support such an analysis. No single model can, of course, capture all the facets of sustainable development at all levels, and for many interactions no models are as yet available. In this chapter, models developed at the Netherlands' National Institute of Public Health and the Environment (RIVM) and the Stockholm Environment Institute (SEI) have been applied to a selected number of environment—development interactions. Through the establishment and operation of a GEO modelling working group (DPCSD, 1996), further models need to be developed and applied on both global and regional scales. This is to ensure more diversity of insights and priorities in future editions of the GEO report e.g. in terms of long-range economic models.

[2] Evidently, there are many other environmental changes and impacts associated with social and economic developments, including emissions of pollutants and waste, and depletion of non-renewable resources. Because of time and resource constraints these issues are not dealt with in detail in this report, which does not even pretend to be comprehensive. Its primary intention is to demonstrate the advantages and feasibility of a model-based assessment. Secondly, important issues such as the environmental implications of inequity, increasing trade volumes and economic globalization are not analyzed in detail beyond the one scenario analyzed in the report.

[3] Uncertainties come in all kinds. There are technical uncertainties related to deficiencies in measurement, and gaps in knowledge about how the human and environmental systems related to the design of the analytical tools used work. There are also uncertainties related to 'unknowable' developments in the future that scenario analysis attempts to address. Finally, there are uncertainties related to people's different interpretation of what is known depending on their perspectives. The results in this chapter have to be seen against the background of these uncertainties. No attempt will be made to quantify the uncertainties or attach probabilities to the results.

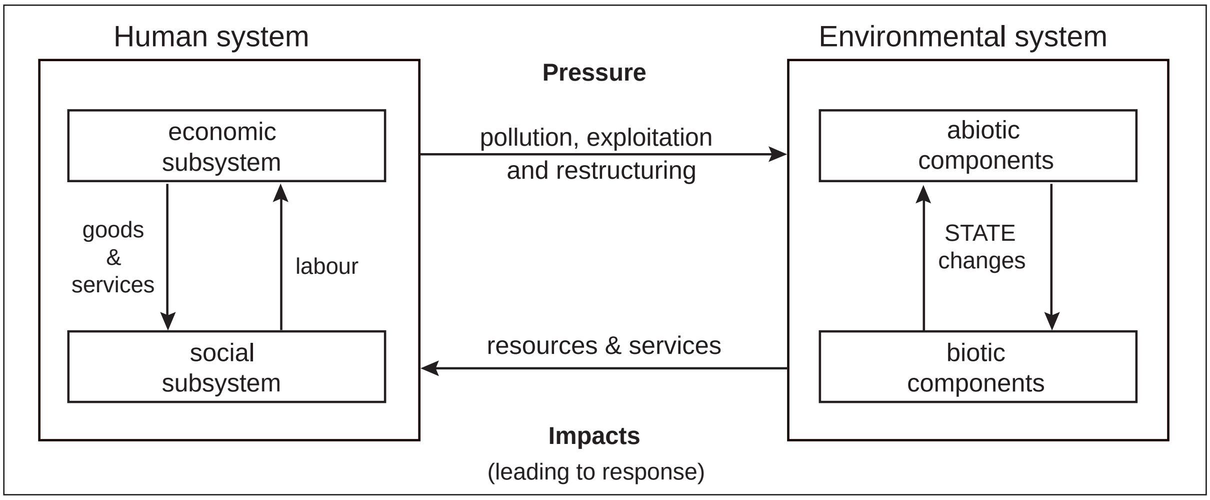


Figure 1.1. *A systems analysis view of the world*
Source: Swart and Bakkes (1995).

Analytical approach

The general approach behind the model-based assessment in this chapter is systems analysis, in particular the analysis of environmental changes that result from interactions between the human and environmental systems (Figure 1.1). It is necessary to ensure that the *social, economic and environmental aspects* of development are, as far as possible, brought onto a level playing field. One way of doing this is to use indicators to summarize the findings[4]. The World Bank distinguishes between human man-made and natural capital (Serageldin, 1996)[5]. However, current understanding of social factors prevents their full and direct inclusion in systems analysis models.

In order to structure the analysis of the interaction between the human and environmental systems, the dynamic nature of these interactive systems are assessed within a *driving forces pressure - state - impact - response framework* (Figure 1.2): Social and economic developments exert pressure on the environment, and, as a consequence, the state of the environment changes. These changes then have impacts on the social and economic functions of the environment, such as the provision of adequate conditions for health, resources availability and biodiversity. Finally, these impacts may elicit a societal response that feeds back on the driving forces (or on the state or impacts directly, through adaptation or curative rather than preventive action).

Obviously, the real world is more complex and dynamic than can be expressed in simple causal relations in systems analysis. There is arbitrariness in the distinction between human and environmental systems, and, depending on the context, a considerable number of phenomena may, for example, play a role as either pressure or impact variable. Moreover, many interactions between environmental and societal systems, and several facets of development, are not sufficiently understood or are difficult to capture in the simple systematic framework shown in Figure 1.2. This is illustrated in Figure 1.3, where the pressure and response elements of the framework are positioned as part of a wider ‘development’ context and two-way interactions are

[4] Indicators are defined here as pieces of information forming part of a specific management process (e.g. in this case the pursuance of sustainable development as outlined in Agenda 21) that can be compared with the objectives of that management process, and have been assigned a significance beyond their face value (Bakkes *et al*., 1994).

[5] However, unlike the World Bank’s monetization of all forms of capital, in this report the different forms of capital are expressed in their own units: ‘monetary’ for economic capital, ‘people’ for human and social capital, and ‘physical’ for environmental capital.

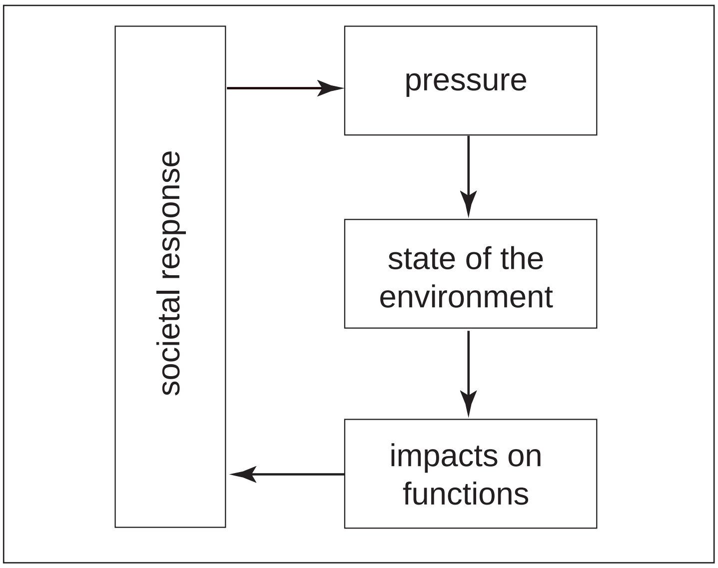


Figure 1.2. *A simple representation of the pressure - state - impact - response framework*
Source: Swart and Bakkes (1995).

indicated instead of the simplified one-way cycle in Figure 1.2. Nevertheless, it is argued here that the simple pressure - state - impact - response cycle does provide an understandable structure within which available knowledge can best be organized and analyzed at this stage (Swart and Bakkes, 1995).

The concept of *transitions* is used to provide a systematic context for describing and understanding the dynamics and interactions between the human and environmental systems. A transition is defined here broadly as a process in which a system undergoes a rapid change, followed by a slow-down to a situation where conditions are qualitatively and quantitatively different from the initial stage. Evidently, this concept has to be applied with care to real-world observations. However, it is used to provide an impressionistic description of some of the major past and possible future developments in the world. The strongly non-linear dynamics of transitions can be understood in terms of the changing relative strength of positive and negative feedbacks (Figure 1.4). In a typical transition, a ‘take-off’ phase represents the early stages of an acceleration, which involves considerable investment efforts and relatively little profit. In this stage, positive feedbacks reinforce the response signal. Policy interventions are the most effective

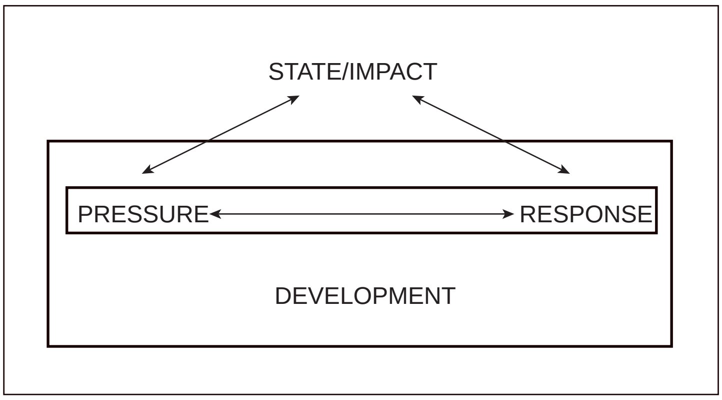


Figure 1.3. *The pressure - state - impact - response framework in the context of development*

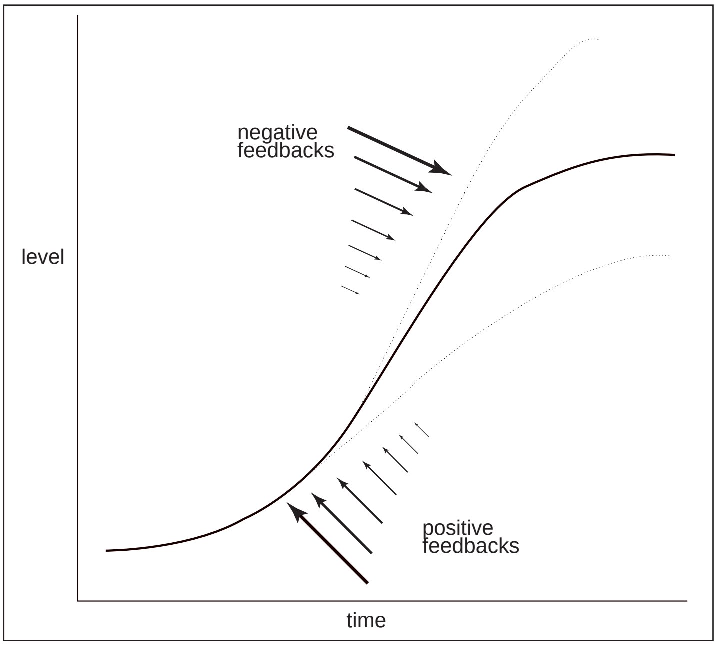


Figure 1.4. *The concept of transitions as a function of positive and negative feedbacks*

here. An 'acceleration phase', characterized by rapid change, follows. This might become autonomous as soon as a threshold value is exceeded and thereby reduce the effectiveness of policy interventions. Finally, negative feedbacks increasing relative to the positive feedbacks within the system lead to a 'stability' phase. Clearly, stability is relative and does not mean permanence: smaller changes can occur and a new transition may follow. The elements of the pressure - state - impact - response cycle can be seen as part of the feedbacks. The Pressure component may trigger the take-off phase of a transition, followed by rapid changes in the State component. This, and the associated instability of the system, may lead to Impacts (positive feedbacks). Policy measures or autonomous Responses may counteract these impacts and dampen the rate of change in the stability phase (negative feedbacks). As we have learned from the past, transitions are no law of nature and, if presented as a historical or future inevitability, would represent a mere example of determinism. Rather, the concept is used here as a stylized way of visualizing and understanding ongoing changes in world dynamics.

Integrated models

In the early seventies, rapid development of computer technology combined with increasing scientific understanding prompted the development of a first generation of systems analysis models attempting to describe and analyze possible future developments in the complex relationships between the various components of the human and environmental system at the global level. UNEP (Swart and Bakkes, 1995) has provided a concise overview of these models. While these models increased understanding and awareness, they had a number of deficiencies related to serious gaps in scientific knowledge at the time and the inherent unpredictability of the future. While the future remains uncertain, new insights can address some of the deficiencies of the first generation of systems models. This has led in the eighties and nineties to the development of new models, some of which were designed to study specific global or regional topics such as acidification and climate change, usually applying the pressure - state - impact - response framework. Others attempt, in addition to the pressure - state - impact - response cycle for a particular theme, to capture as many interlinkages as possible between the economic, social and environmental systems on a global scale. Some of these computer models are used in this chapter.

The IMAGE model, supplemented by RAINS and TARGETS model calculations, functioned as the basic model for the assessments in this report (see also Appendix III). PoleStar had been used in the compilation of the scenario to enhance consistency between the different components of the driving forces in SEI's accounting framework. RIVM's IMAGE model and the RAINS model (developed at IIASA) are applied jointly to analyze the interaction between climate change and acidification. RIVM's TARGETS model is applied to illustrate the interlinkages between the systems' components at a long-term aggregate level. Results from the TARGETS Health and Population submodel are also reported. The IMAGE model is also used to provide a provisional sketch of the technical space allowed for enhanced policies, described in chapter 7. These models are briefly described in Appendix III. Furthermore, results from the Asian Integrated Model (AIM) of the Japanese National Institute of Environmental Studies (NIES) are used in this report.

The aim of the current analysis is to explore the environmental risks of selected socioeconomic developments after the 'Rio conference'. At this stage, no rigorous analysis of different response scenarios using economic models will be attempted. (However, UNEP in collaboration with DPCSD and other organizations, are setting up a Global Modelling Forum for global modelling activities to analyze Agenda 21-related issues, including economic analysis. See also Appendix I) Of course, model-based analysis does not provide specific answers to today's pressing questions but does provide structure, consistency and, hopefully, a better understanding of the complexity of these questions so as to support rather than replace decision-making. Other contributions to GEO will obviously address the key questions from a different perspective in different ways.

Scenario analysis

Current environmental problems are, to a large extent, caused by human activities in the past, while future difficulties are being generated now. Therefore, in the next chapter, historical trends will be briefly discussed to provide a better understanding of the causes of environmental changes and the relative contributions of the various regions. It is also crucial to note that the response of both societal and environmental systems to changes in other systems is necessarily delayed. (The delays are caused by factors ranging from residence times of chemicals in the environment, to depreciation times of the capital stock and to the time it takes to educate and train the next human generation.) One consequence of this is that to identify emerging issues and priorities, and to analyze the implications of alternative policy strategies, it is necessary to assess a wide range of possible future developments. This is done using scenarios.

Scenarios are hypothetical sequences of events, constructed for the purpose of focusing attention on causal processes and decision points (Kahn and Wiener, 1967). They are descriptions of alternative futures, possibly based on different views of how the world works. Thus scenarios are images of the future created from mental maps or perspectives on the past and present. They are not deterministic predictions of what is likely to occur or what should occur, nor are they stories about the future akin to science fiction or probabilistic ranges around a central trend. The role of scenarios is to examine different perspectives, to challenge conventional thinking and to offer a systematic and disciplined way of discussing crucial issues. Different possible policy strategies can also be analyzed by way of scenarios. The selection of the scenario is <u>not</u> a choice for or against a certain future. The development and selection of scenarios is an iterative process involving users and analysts.

In deviation from the principle that scenario analysis should consider alternative futures, the present analysis for the first Global Environment Outlook is only applied to one scenario, the so-called Conventional Development scenario (see Chapter 2). This is because of the present lack of sufficiently elaborated global scenarios. However, this limitation should not be explained in the sense that the Conventional Development Scenario would be more plausible or desirable than other futures. Meanwhile, UNEP has set up yet another Global Working Group to address this gap (see Box 2.1 in Chapter 2).

North and south, past and future

Time is also important in another respect. In the international debate about environment and development, the industrialized countries in the North have focused primarily on environment and sustainability, whereas the developing countries in the South emphasize the importance of economic growth and development. From the perspective of industrialized countries, the momentum of population and economic growth in the South foreshadows future global environmental degradation. The South, with primarily short-term economic and local environmental problems to address, places these global environmental concerns primarily in the context of the asymmetric distribution of impacts and responsibilities: the main risks in the South, and the past and present responsibilities in the North. For this reason, this analysis supporting the Global Environment Outlook has to consider not only the future, but also the past and present. Evidently, the future will be different from the past. However, one can learn both from the past, as the origin of the main driving forces of the global societal and environmental changes, and from the way in which interactions between system components have evolved.

1.2 A world in transition

Introduction

How can the above concepts and methods[6] be combined to provide a systematic and comprehensive framework for exploring the key issues set out at the beginning of this chapter? A dynamic framework of linked social, economic and environmental transitions is envisaged to address this question. Box 1.1 provides a model-based illustration.

Referring to the illustration in Box 1.1, transitions in population and economic dynamics are discussed first, followed by changing demands for energy, raw materials, food and water, derived from developments in population and economy. Third, possible implications of these demands for the environment are considered, taking into account transitions in the type and efficiency of resource use. Finally, closing the loop, it has been established that important elements of human response be implicate or explicate included in forward projections.

Social and economic resources: dynamics of population and production

The dynamics of the *human population* are sufficiently well understood to estimate fairly precisely its expected development over the next two to three decades. In the longer term, it is much more difficult to predict the pathway along which a demographic transition may take place. Almost all researchers, however, agree that there will be a further decline in birthrates along with declining death rates. This will result in a population growth moving towards some 10 billion people by the end of next century . As important as the numbers is the quality of human life for which life expectancy and disease-adjusted life expectancy are widely used as indicators. These are determined by a complex pattern of social and economic changes, ranging from income distribution, and literacy, as well as access to safe water, sanitation and medical services. If the correlations observed in the past between such patterns, and a general indicator of economic welfare like GDP per capita, are accepted as a rough guide for the future, a further increase in disease-adjusted life expectancy is to be expected. In effect, the trajectories shown in Box 1.1

[6] Pressure-state-impact-response framework; social, economical and environmental systems; transitions; integrated models; and scenarios.

combine two transitions: the demographic and the epidemiological. These global smooth curves hide significant regional variations.

The *economic system* constitutes the second major driving force in the global human-environment system. Driven by the re-investment of some of the industrial output and sales of natural resources into agricultural and manufacturing production facilities, this economic growth process feeds on a stream of productivity-raising innovations and a gradual infrastructural unfolding of roads, schools, hospitals and other facilities. Together, these comprise the stocks of man-made capital. It is well acknowledged that the adequate functioning of this man-made capital has to be accompanied by investments to maintain and enhance other, less tangible forms of capital. This comprises what is called 'human capital' (including aspects such as education) and maybe even 'social capital' (such as community and governance structures) as well. It has become equally evident that the system can only be sustained by a continuous influx of energy and material derived from 'environmental capital'. History has shown time and again that a proper balance between these three forms of capital and their use is an important condition for the human aspiration to a healthy, fulfilling and prosperous life. Underlying the growth of aggregate economic output is the transition from a largely agricultural to an industrial economy, and then towards a service and information-oriented economy - the economic transition (compare Box 1.1, see also Maddison, 1991).

Derived demands for energy, raw materials, food and water

The mutually interacting dynamics of human population and economic growth will be henceforth referred to as pressure components, generating a demand for food, water, energy and raw materials. These derived demands, as they are called in the economic sciences, have to be delivered by a great variety of natural systems. Given the common expectation of population and economic growth (Box 1.1), one can make forward projections of the demand for food, water and energy. A common procedure is to use the present intensities, measured as physical fluxes per unit of activity, to depict a future in which there are no qualitative changes apart from population and economic transitions. This would, at least after some time, lead to a slow decline in the growth of the demand for food, water, energy and raw materials due to the dynamics of the demographic and epidemiological transition, and the relatively low intensity of services and information-oriented activities. To meet the derived demands, part of the economic output must be invested in the expansion and maintenance of the capital stocks (agricultural land and equipment for the supply, transport and processing of water and fuels) that generate these outputs. Clearly, the assumption of constant intensities is at odds with the historical evidence, which suggests that these intensities are also subject to transitions. For food, there are the trends to a higher share of meat in the average diet and to more processing; in agriculture, the trend is to more intensive farming. Water demand is expected to rise parallel to increased access to safe water, while at the same time water intensity may start to decline, as is already evidenced by current developments in water treatment, re-use and irrigation. For energy, the trend towards increasing intensity with the onset of industrialization is reversed once services and information-oriented activities start to dominate, and new and more efficient technologies diffuse to new users.

The changes in intensity reflect a complex pattern of economic, social and cultural changes intricately related to the quality of human life and underlying aspirations and values - as is the case with population transitions. Hence, their historical interpretation is controversial and their future development is hotly disputed. Obviously, calculation of the food, water and energy intensities is fraught with controversies and uncertainties. Yet, using prevailing insights and expectations, it is possible to make reference projections of plausible transitions. From the illustrative model simulations presented in Box 1.1, we can see two major features for food: 1) food intake per capita may be slowly saturated and 2) the fraction of animal products in the average diet is likely to increase. For health expenditures, another determinant of demographic changes, a persistent rise over the next century has already begun. For water, the key components number an increase in public water supply and in the water used by industry. For energy, the most important aspects of a possible transition are the decreasing energy use per unit of economic output and the shift away from carbon-based fuels, both after an initial period of increase.

Environmental pressures

Combining these intensities with the demographic and economic developments yields the simulated time path for the use of important natural capital stocks and flows: arable land, water reservoirs and fluxes, and energy resources and fluxes. This by a set of important pressures on the environment which result from the need to satisfy the demands for food, water, energy and raw materials. These include the amount of fertilizer used in agriculture, the amount of polluted water discharged onto surface waters and the emissions of various substances into the air (Box 1.1).

The changing state of the environment

Will the earth be able to meet humanity's demand for these resources in a sustainable manner? This question can only be explored on the basis of the best available, yet still deficient insights into the operation of the earth's life-support systems. Even then, in view of the normative nature

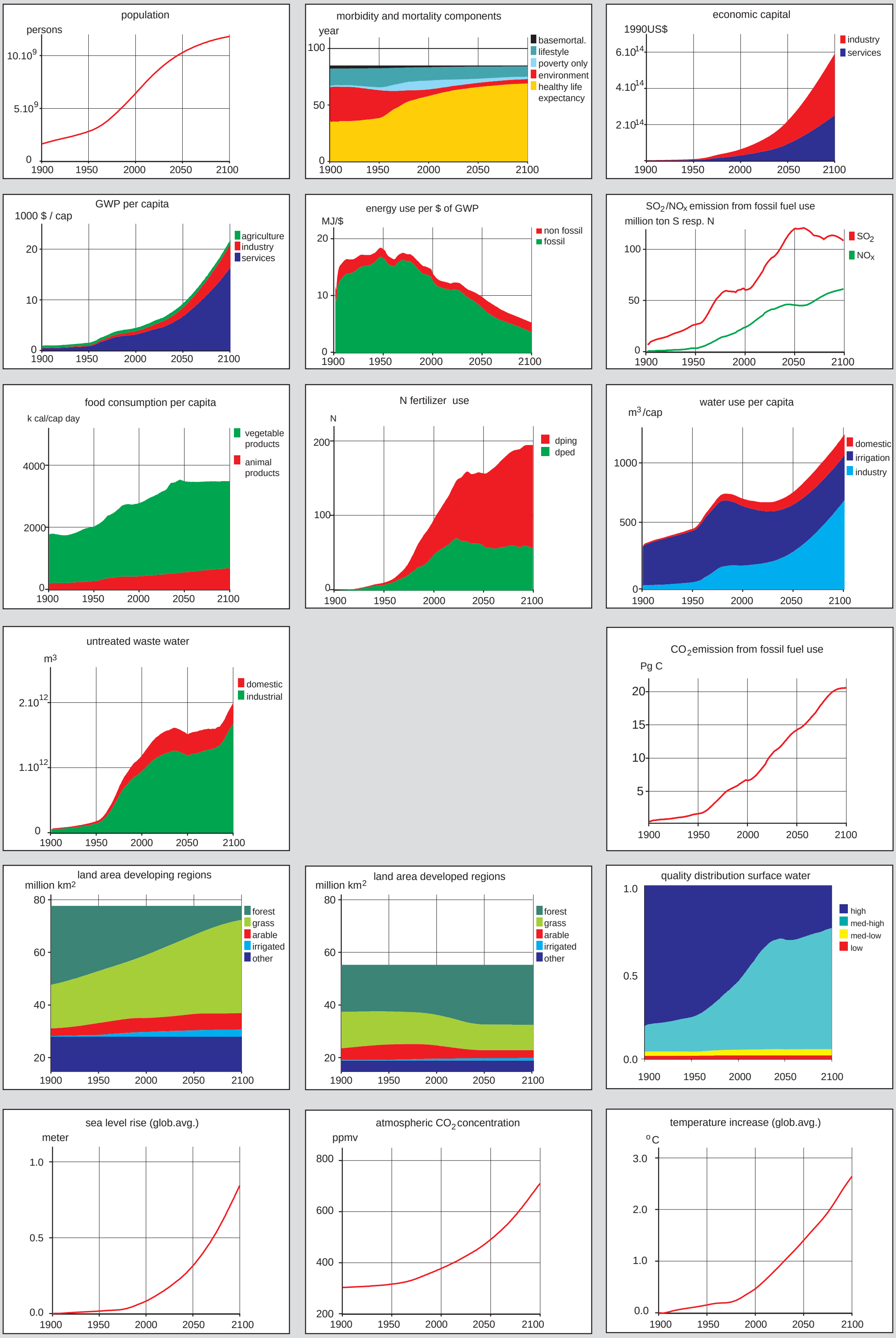
Box 1.1 *A World in Transition: a model-based exploration of linkages*

This chapter proposes a framework of linked social, economic and environmental transitions to provide one possible way of organizing and analyzing the complex relationships between different aspects of world development and the sustainability of these relationships. The graphs in this box illustrate these relationships for a kind of 'middle of the road' scenario for long-term developments at the global aggregate level using a systems analysis approach. The model has been calibrated using historical data for the period 1800-1990. Derived from preliminary analysis with the TARGETS model (for a model description see Appendix III), the graphs emphasize the relationships, not data or figures. From left to right, the graphs illustrate possible linkages between different system components, such as different environmental compartments (Rotmans and de Vries, 1997). From top to bottom, the graphs illustrate a chain involving driving forces, derived demands, environmental pressure, a changing state of the environment and impacts. Various responses are part of the overall dynamics but not shown here.

The top graphs illustrate possible developments of the driving forces population and economy; they also include the notions of a demographic transition towards higher healthy life expectancy and a growing economy that changes its composition from agricultural through industrial to service-dominated. The derived demands for energy, raw materials, food and water can be characterized by a 'transition' towards greater efficiency. At the global level, the associated environmental pressures are related to these demands through decreasing emissions or landuse changes per unit of demand and increasing resource productivity. This process will be fastest for pressures that can be mitigated relatively easily, such as sulphur emissions, slower for other emissions, such as nitrogen oxides, and as in the example, slowest for greenhouse gases. The resulting changes in the state of the environment and associated impacts are dependent on whether, and if so, how and how fast, these transitions take place. Implicitly, any forward calculation, like the hypothetical one in the graphs, includes important response elements.

The illustrations are not intended to describe the most likely future, nor a desirable one. In the real world, developments will be different from those in the illustrations. Perhaps even more important, they will be very different at the regional and subregional levels, dependent on regional and subregional characteristics. Different developments of the various feedback processes - including the ways they are influenced by human choices - lead to different shapes of the curves. The illustrate the importance of the linkages between the social, economic and environmental components of a world that is undergoing rapid changes. The analysis of the linkages suggests that in some instances social, economic and environmental goals may be compatible. In other cases, trade-offs seem unavoidable.

***Box 1.1** continued*



of the notion of sustainability, any answer to this question will contain value-loaded judgments. The supply of food, both for humans and animals, will cause a further extension of the land used for cultivation (Box 1.1). Use of inputs per ha may rise steadily too, leading to higher yields. Effluents to land and water will increase, especially with regard to nitrogen compounds. Placing higher demands on water resources will lead to an increase in the average costs of supplying water and to a decline in the available groundwater. Finally, the supply of energy in various forms will cause a decline in the fossil-fuel resource base. Supply costs are expected to eventually increase as the high costs of new deposits are no longer compensated for by cost-reducing innovations. New sources and technologies will slowly penetrate into the market which, in combination with abatement measures, will tend to slow down or reverse current trends in emissions of carbon, sulphur and nitrogen compounds (Box 1.1).

The changes in environmental capital are related in complex ways to a whole set of characteristics, the change of which impacts on the human-economy system. Some of these interfere directly with its functioning, while others have a less direct impact in the sense that they have to be accommodated by altering the patterns of activities and investments.

Mutual interactions between changes and responses

Finally, the illustrative projection reported in Box 1.1 already contains important elements of human response behaviour. Declining productivity of land is counteracted by additional fertilizer use; the rising marginal costs of water supply require additional investments; depletion of fossil-fuel resources combined with the expectation of global warming encourages energy conservation and a switch to renewable energy sources.

It is possible to evaluate different transition paths, which have an ‘acceptable’ impact on the natural environment, in the provision of energy, materials, food and water resulting from the same driving forces scenario. Acceptability here is interpreted in the context of Agenda 21 statements about the quest for sustainable development. Several possible orientations for this exploration are indicated in this report, but contributions to future editions of the GEO are envisaged to elaborate further on these issues. Two general remarks are pertinent here. First, the economic, political and cultural circumstances needed for successful implementation of desirable transitions are not extensively discussed in this report. Nor is it suggested that they involve major or disruptive political measures or socioeconomic changes. In fact, some of the transitions may already have started and may evolve further as a consequence of current or emerging technologies, insights and attitudes. Second, this chapter does not analyze the feedbacks that would result from the transitions discussed or from the impacts of the socioeconomic driving forces through the environment system. The reason for this is that these feedbacks are extremely complex - including changes in trade and consumption patterns, and income distribution within and between nations.

Using the mental framework illustrated above, the following chapters explore possible developments at global and regional levels for a number of selected themes using a different, more detailed scenario for future developments.

1.3 Structure of this report

This report focuses primarily on the period 1970-2015. This is because reliable historical data are often only generally available from 1970 onwards and the year 2015 is believed to match the time perspective of decision-makers. In the assessment, this time period is placed in the perspective of the 1900-2050 period to account for the significance of the slow-moving dynamics in environmental and socio-economic developments, while acknowledging the historical data before 1950 as less certain and making the scenario assumptions beyond 2015 even more speculative.

The findings of the analysis are reported in terms of six regions, corresponding with the division of the UNEP regional offices (Figure 1.5).

This chapter has been structured using the pressure - state - impact - response framework. Questions asked are:
- How will socioeconomic driving forces affect freshwater and land resources, and how will these changes mutually interact, for example, through element cycles? (Figure 1.6).
- Why are these changes important for society?

To begin with, Chapter 2 deals with the development of the social and economic driving forces. Chapters 3 and 4 discuss how this pressure influences selected aspects of the environment. Chapter 3 alone addresses the importance of selected elements of the interacting global element cycles for environmental quality, while Chapter 4 addresses land resources, their potential for food production and associated dependence on freshwater resources. The impacts on selected components of natural areas (Chapter 5) and society (Chapter 6) are subsequently addressed. Finally, Chapter 7 looks at how society can respond to these projected changes. The appendices provide background information on the data, models and scenarios used.

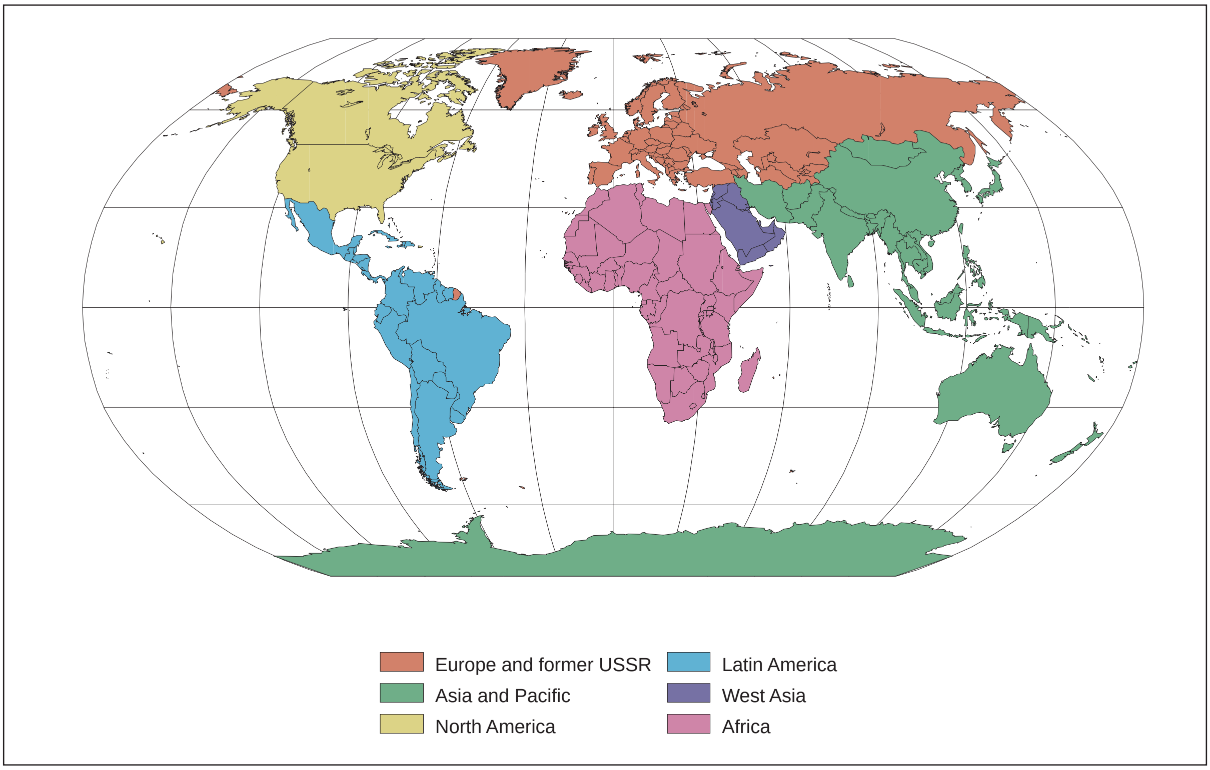


Figure 1.5. *GEO regional breakdown*

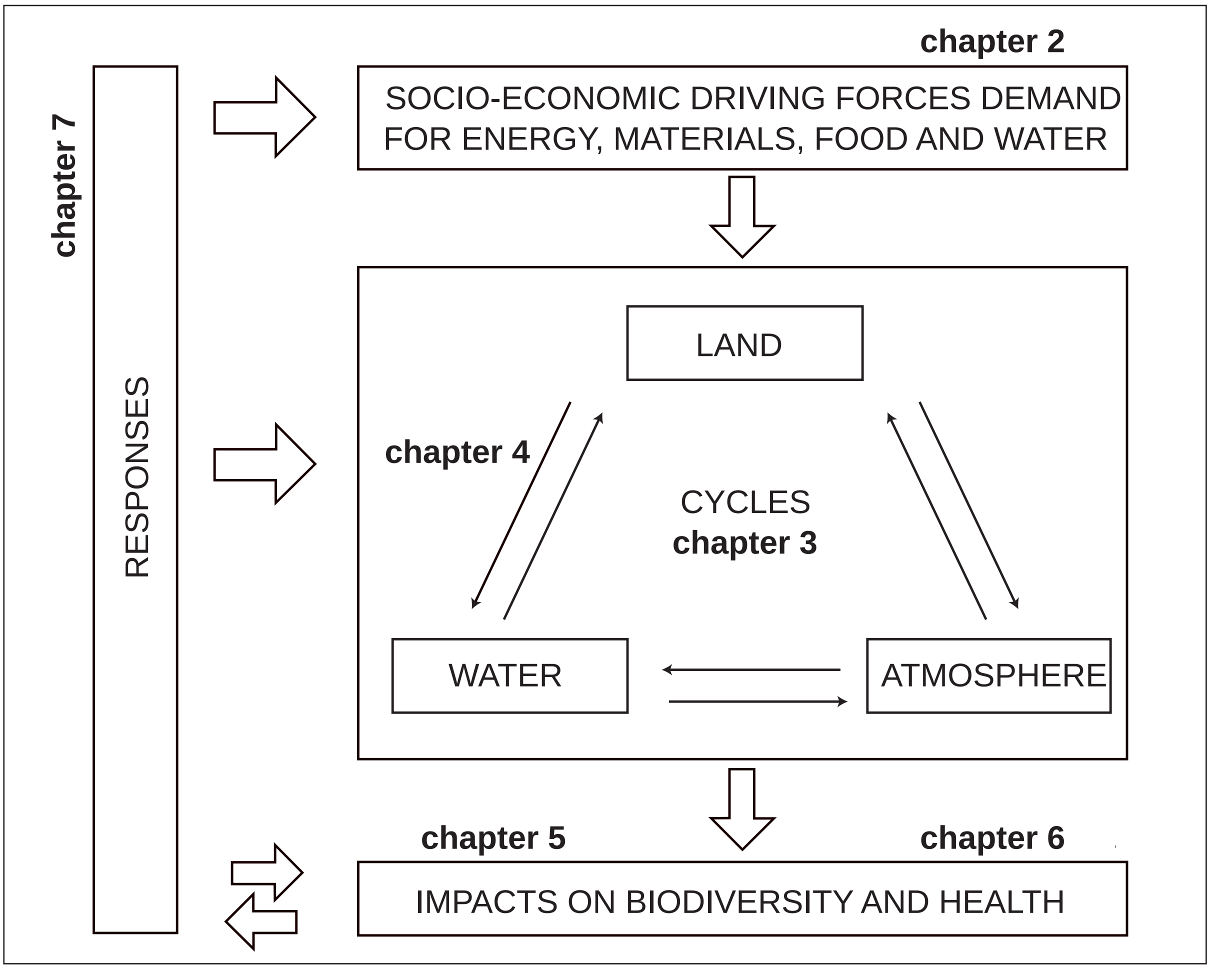


Figure 1.6 *Elements of the pressure-state-impact-response framework covered in this report*

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2 ENVIRONMENTAL PRESSURE: SOCIOECONOMIC DRIVING FORCES AND DERIVED DEMANDS

2.1 The issue

Introduction

This chapter focuses on the pressure element of the pressure-state-impact-response cycle. The main cause of pressure on the environment is the growing demand for energy, raw materials, food and water. The basic driving forces behind this demand are increased production and consumption, and population growth. Pressures on the environment resulting from these driving forces and derived demands have led to a change in land cover around the world and a depletion of the stocks of natural resources and ecosystems. More recently, there has been a significant disturbance of natural cycles and fluxes of substances like nutrients and toxic compounds between the environmental compartments (land, water and the atmosphere). From the perspective of environmentally sustainable development, it is crucial to understand the linkages between driving forces and their consequences. To do this, it is necessary, first of all, to take a look at the past[1]. Scenario analysis methods will then be applied to explore how these linkages and developments may turn out in the future.

The previous chapter introduced the concept of transitions. From a historical perspective, two types of transitions in the socioeconomic driving forces can be inferred. The first is an economic transition: from an often inequitable, agriculture-based economy through a phase of material-intensive industrialization towards a more equitable, service-based and material-extensive economy. Some industrialized countries are in an advanced stage of this transition. The second is the related health transition[2] from a low-density, agricultural-based society with high fertility and mortality rates in which communicable diseases are the main cause of poor health, through to an industrialization phase, with decreasing mortality rates, and on to an urbanized, service-based society with low fertility and mortality rates and where the trend has shifted to chronic diseases. It is uncertain whether and, if so, when, other regions want to, or will be able to, go through the same type of transitions.

In the previous chapter the concept of transition was broadened beyond the economic and health transitions so as to catch environmental changes in the fields of energy, raw materials, land and water too. For example, in the energy field, a major transition from renewable to fossil fuels took place in the past, while a new transition to a different energy system may take place in the future, meaning a possible return to renewable sources as a result of environmental concerns or - eventually - due to a scarcity of fossil fuels. Concerning land, the transition of predominantly non-domesticated lands to tightly planned and managed domesticated land use has now taken place in many regions. In the following chapters, these and other changes will be discussed in more detail.

A multitude of economic, technological and environmental forecasts has been developed. However, most of these are limited in scope, either focusing on a particular subsystem or theme (population, economy, energy and climate change, etc.). A conventional development scenario is used in this report to describe one possible future for (1) the growth of population and economies

[1] Information on the past has been used to calibrate the models. The model used most extensively for this chapter, RIVM's IMAGE model, has been calibrated against post-1950 data on the economy, demography, energy and land use, while improved calibration using a 100-year database is currently in progress (Klein Goldewijk and Battjes, 1995).

[2] Health transition comprises demographic and an epidemiological transitions.

Table 2.1. *Selected historical data and scenario assumptions, absolute figures*

	1950	1990	2015	2050	1950-1990 %	1990-2015 %	2015-2050 %
Population (in billions)							
Africa	0.22	0.64	1.26	2.20	2.7	2.7	1.6
Asia & Pacific	1.32	2.93	4.07	5.16	2.0	1.3	0.7
Europe	0.57	0.79	0.86	0.89	0.8	0.4	0.1
Latin America	0.16	0.45	0.64	0.82	2.5	1.5	0.7
North America	0.17	0.28	0.32	0.33	1.3	0.6	0.1
West Asia	0.07	0.20	0.41	0.73	2.7	2.9	1.6
Developed regions	0.74	1.07	1.18	1.22	0.9	0.4	0.1
Developing regions	1.77	4.21	6.38	8.91	2.2	1.7	1.0
World	2.51	5.28	7.56	10.13	1.9	1.4	0.8
Gross Domestic Product (in trillion 1990 US$)	**1950**	**1990**	**2015**	**2050**	**1950-1990**	**1990-2015**	**2015-2050**
Africa	0.1	0.4	1.0	4.3	3.6	3.6	4.2
Asia & Pacific	0.4	4.7	12.0	30.8	6.4	3.9	2.7
Europe	1.7	8.1	15.1	27.3	4.0	2.5	1.7
Latin America	0.2	1.1	2.4	6.9	4.7	3.1	3.0
North America	1.7	6.0	13.1	21.6	3.2	3.1	1.4
West Asia	0.1	0.6	1.6	6.9	5.3	4.1	4.3
Developed regions	3.4	14.2	28.1	48.9	3.6	2.8	1.6
Developing regions	0.8	6.8	17.0	47.1	5.6	3.7	3.0
World	4.2	21.0	45.1	96.0	4.1	3.1	2.2
Primary energy* consumption (in EJ)	**1950**	**1990**	**2015**	**2050**	**1950-1990**	**1990-2015**	**2015-2050**
Africa	1.2	7.4	16.5	58.9	4.6	3.3	3.7
Asia & Pacific	4.8	68.7	185.1	336.1	6.9	4.0	1.7
Europe	30.7	129.9	185.5	205.5	3.7	1.4	0.3
Latin America	1.9	14.3	25.1	55.4	5.1	2.3	2.3
North America	37.4	88.8	132.7	121.6	2.2	1.6	-0.2
West Asia	0.4	11.4	26.4	59.1	8.8	3.4	2.3
Developed regions	68.1	218.8	318.1	327.1	3.0	1.5	0.1
Developing regions	8.4	101.8	253.2	509.5	6.4	3.7	2.0
World	76.5	320.6	571.3	836.6	3.6	2.3	1.1
Caloric intake (in trillion kcal/day)	**1970**	**1990**	**2015**	**2050**	**1970-1990**	**1990-2015**	**2015-2050**
Africa	0.8	1.5	3.2	6.2	1.6	3.1	1.9
Asia & Pacific	4.1	7.3	10.8	14.1	1.4	1.6	0.8
Europe	2.3	2.7	3.0	3.1	0.4	0.3	0.1
Latin America	0.7	1.2	1.8	2.4	1.3	1.6	0.9
North America	0.7	1.0	1.2	1.2	0.8	0.6	0.1
West Asia	0.3	0.6	1.2	2.2	1.9	3.0	1.7
Developed regions	3.0	3.7	4.1	4.3	0.5	0.4	0.1
Developing regions	5.9	10.5	17.0	24.9	1.5	1.9	1.1
World	8.9	14.3	21.1	29.1	1.2	1.6	0.9
Total water withdrawal (in 1000 km^3/yr)	**1950**	**1990**	**2015**	**2050**	**1950-1990**	**1990-2015**	**2015-2050**
Africa	n.a.	0.15	0.20	0.28	n.a.	1.3	1.0
Asia & Pacific	n.a.	1.30	1.65	2.05	n.a.	1.0	0.6
Europe	n.a.	0.72	0.87	0.91	n.a.	0.8	0.1
Latin America	n.a.	0.18	0.24	0.30	n.a.	1.2	0.7
North America	n.a.	0.51	0.58	0.57	n.a.	0.5	0.0
West Asia	n.a.	0.13	0.17	0.21	n.a.	1.1	0.7
Developed regions	n.a.	1.23	1.45	1.49	n.a.	0.7	0.1
Developing regions	n.a.	1.75	2.26	2.84	n.a.	1.0	0.7
World	n.a.	2.98	3.72	4.33	n.a.	0.9	0.4
Energy intensity (in MJ/1990 US$)**	**1950**	**1990**	**2015**	**2050**	**1950-1990**	**1990-2015**	**2015-2050**
Africa	12.1	17.9	16.4	13.7	1.0	-0.4	-0.5
Asia & Pacific	12.2	14.7	15.4	10.9	0.5	0.2	-1.0
Europe	17.9	16.0	12.3	7.5	-0.3	-1.0	-1.4
Latin America	10.5	12.5	10.3	8.0	0.4	-0.8	-0.7
North America	21.7	14.7	10.1	5.6	-1.0	-1.5	-1.7
West Asia	5.3	20.0	16.8	8.6	3.4	-0.7	-1.9
Developed regions	19.8	15.4	11.3	6.7	-0.6	-1.2	-1.5
Developing regions	11.1	15.0	14.9	10.8	0.8	0.0	-0.9
World	18.2	15.3	12.7	8.7	-0.4	-0.8	-1.1
Production of Maize (in Tg)	**1970**	**1990**	**2015**	**2050**	**1970-1990**	**1990-2015**	**2015-2050**
Africa	21.4	36.7	82.7	186.8	2.7	3.3	2.4
Asia & Pacific	49.2	116.6	220.5	296.5	4.4	2.6	0.8
Europe	46.1	70.5	91.8	121.0	2.1	1.1	0.8
Latin America	36.8	55.9	91.6	153.7	2.1	2.0	1.5
North America	125.3	202.1	224.1	251.5	2.4	0.4	0.3
West Asia	1.8	3.1	4.3	3.8	2.7	1.3	-0.4
Developed regions	171.4	272.6	315.9	372.5	2.3	0.6	0.5
Developing regions	109.2	212.3	399.0	640.7	3.4	2.6	1.4
World	280.6	484.9	714.9	1013.2	2.8	1.6	1.0

*   Exclusive of modern biofuels (compare Figure 2.5)
**   Energy intensity = Primary energy consumption divided by Gross Domestic Product
n.a.   = data not available

Table 2.2. *Selected historical data and scenario assumptions, per capita*

	1950	1990	2015	2050	1950-1990 %	1990-2015 %	2015-2050 %
Gross Domestic Product per capita (in 1000 $/cap; (1990 US$))							
Africa	0.5	0.6	0.8	2.0	0.8	0.9	2.6
Asia & Pacific	0.3	1.6	2.9	6.0	4.3	2.5	2.0
Europe	3.0	10.3	17.5	30.5	3.1	2.1	1.6
Latin America	1.1	2.6	3.8	8.4	2.1	1.6	2.3
North America	10.4	21.8	40.8	65.5	1.9	2.5	1.4
West Asia	1.1	2.8	3.8	9.5	2.5	1.2	2.6
Developed regions	4.7	13.3	23.8	40.0	2.7	2.4	1.5
Developing regions	0.4	1.6	2.7	5.3	3.4	2.0	2.0
World	1.7	4.0	6.0	9.5	2.2	1.6	1.3
Primary energy* consumption per capita (in GJ/cap)	**1950**	**1990**	**2015**	**2050**	**1950-1990**	**1990-2015**	**2015-2050**
Africa	5.6	11.6	13.2	26.8	1.8	0.5	2.1
Asia & Pacific	3.6	23.5	45.5	65.1	4.8	2.7	1.0
Europe	53.7	164.5	215.1	229.9	2.8	1.1	0.2
Latin America	11.8	32.1	39.2	67.6	2.5	0.8	1.6
North America	225.3	321.2	414.2	368.5	0.9	1.0	-0.3
West Asia	5.6	56.5	64.3	81.4	5.9	0.5	0.7
Developed regions	92.3	205.1	269.0	267.3	2.0	1.1	0.0
Developing regions	4.7	24.2	39.7	57.2	4.2	2.0	1.0
World	30.5	60.7	75.6	82.6	1.7	0.9	0.3
Caloric intake per capita (1000 kcal/cap day)	**1970**	**1990**	**2015**	**2050**	**1970-1990**	**1990-2015**	**2015-2050**
Africa	2.2	2.4	2.6	2.8	0.4	0.3	0.3
Asia & Pacific	2.1	2.5	2.7	2.7	0.9	0.3	0.1
Europe	3.3	3.4	3.4	3.4	0.3	0.0	0.0
Latin America	2.5	2.7	2.8	2.9	0.4	0.2	0.1
North America	3.2	3.6	3.7	3.6	0.6	0.0	0.0
West Asia	2.4	2.9	3.0	3.0	0.9	0.1	0.0
Developed regions	3.3	3.5	3.5	3.5	0.4	0.0	0.0
Developing regions	2.1	2.5	2.7	2.8	0.8	0.3	0.1
World	2.4	2.7	2.8	2.9	0.6	0.1	0.1
Total water withdrawal per capita (in 1000 m^3/cap yr)	**1950**	**1990**	**2015**	**2050**	**1950-1990**	**1990-2015**	**2015-2050**
Africa	n.a.	0.23	0.16	0.13	n.a.	-1.4	-0.6
Asia & Pacific	n.a.	0.44	0.41	0.40	n.a.	-0.4	-0.1
Europe	n.a.	0.91	1.01	1.02	n.a.	0.4	0.0
Latin America	n.a.	0.40	0.38	0.37	n.a.	-0.3	-0.1
North America	n.a.	1.85	1.82	1.74	n.a.	-0.1	-0.1
West Asia	n.a.	0.64	0.41	0.29	n.a.	-1.8	-1.0
Developed regions	n.a.	1.15	1.23	1.21	n.a.	0.3	0.0
Developing regions	n.a.	0.42	0.35	0.32	n.a.	-0.6	-0.3
World	n.a.	0.56	0.49	0.43	n.a.	-0.5	-0.4
Energy intensity per capita (in J/$ cap; (1990 US$))**	**1950**	**1990**	**2015**	**2050**	**1950-1990**	**1990-2015**	**2015-2050**
Africa	55.3	28.0	13.0	6.2	-1.7	-3.0	-2.1
Asia & Pacific	9.2	5.0	3.8	2.1	-1.5	-1.1	-1.7
Europe	31.2	20.2	14.3	8.4	-1.1	-1.4	-1.5
Latin America	64.1	28.0	16.1	9.8	-2.0	-2.2	-1.4
North America	130.8	53.2	31.7	17.0	-2.2	-2.1	-1.8
West Asia	77.1	99.1	40.9	11.8	0.6	-3.5	-3.5
Developed regions	26.8	14.5	9.6	5.5	-1.5	-1.6	-1.6
Developing regions	6.3	3.6	2.3	1.2	-1.4	-1.7	-1.8
World	7.3	2.9	1.7	0.9	-2.3	-2.2	-1.9
Production of Maize (in kg/cap)	**1970**	**1990**	**2015**	**2050**	**1970-1990**	**1990-2015**	**2015-2050**
Africa	98.0	57.3	65.8	85.0	-2.6	0.6	0.7
Asia & Pacific	37.3	39.9	54.2	57.4	0.3	1.2	0.2
Europe	80.6	89.3	106.4	135.3	0.5	0.7	0.7
Latin America	224.3	125.4	143.3	187.6	-2.9	0.5	0.8
North America	755.0	730.7	699.7	762.2	-0.2	-0.2	0.2
West Asia	26.5	15.3	10.4	5.2	-2.7	-1.5	-2.0
Developed regions	232.3	255.6	267.1	304.4	0.5	0.2	0.4
Developing regions	61.6	50.4	62.6	72.0	-1.0	0.9	0.4
World	111.8	91.8	94.6	100.0	-1.0	0.1	0.2

* Exclusive of modern biofuels (compare Figure 2.5)
** Energy intensity = Primary energy consumption divided by Gross Domestic Product
n.a. = data not available

in the world's regions, (2) the associated demand for energy and resulting emissions and (3) the demand for food and water. This scenario has been derived by the Stockholm Environment Institute (Raskin *et al*., 1995a) from the demographic, economic and energy assumptions of the mid-range IPCC non-intervention scenario IS92a (Leggett *et al*., 1992) and supplemented with estimates for relevant factors not covered by IPCC, notably water withdrawals, caloric intakes and associated changes in land use, and emissions of toxic substances. (The latter will not be discussed in this report.)

Many important social factors (such as education, culture and institutions) are not explicitly taken into account by the scenario[3]. The consistency of the assumptions in the different sectors has been enhanced by using SEI's global accounting framework, PoleStar (Raskin *et al*., 1995c)[4]. Table 2.1 summarizes selected key assumptions in absolute terms, along with regionally and globally averaged rates of change. Table 2.2 shows key variables on a per capita basis. In no way is it intended to promote or approve the scenario implications. The scenario is used as the basis for a 'what-if' model-based analysis and is certainly not endorsed by UNEP as a likely or desirable future within the time-frame of the first GEO. A wider set of more comprehensive and diverse scenarios of global development with adequate international support could not be developed and analyzed (see Box 2.1). This has been a major handicap for the present study because it removes the possibility of demonstrating how scenario analysis can support *ex ante* evaluation of alternative futures and of policy options. It has also been commented that IPCC's IS92a scenario, on which the CD scenario is largely based, no longer adequately reflects economic trends in various regions of the world. Given this handicap, some material has been included in this report to emphasize the importance of considering alternative scenarios and policy responses. First, there is the ongoing work of the GEO Global Scenario Working Group, on other 'possible' futures (Gallopin *et al*., 1996). Box 2.1 contains some early illustrations. Second, two variants to the Conventional Development Scenario have been formulated and briefly analyzed. Chapter 7 reports on the findings. These variants are in no way fully developed, consistent and realistic alternatives to the CD scenario, but they do illustrate the technical space for changes leading to a more sustainable world.

For the analysis presented in this report, the original scenario needed further interpretation. Details on this can be found in Appendix II. The time horizon for the analysis had been specified by UNEP's Governing Council as the year 2015, i.e. one generation from now. However, as several transitions may become more noticeable later ('system delays'), a projection to the year 2050 has been added as a second horizon. Obviously, certain changes assumed in the Conventional Development (e.g. in population, emissions) will have substantial impacts in the second half of the next century, i.e. beyond the 2050 horizon.

[3] In the Conventional Development scenario the development of per capita income is only described at the regional level; it does not specify intra-regional income distribution. With respect to demographic developments, the CD scenario neither geographically explicitly defines population densities (apart from a split between urban and rural) nor migration fluxes. As a consequence, the scenario does not allow for the quantitative evaluation of related social or environmental impacts, like malnutrition, loss of good health and poverty-related environmental degradation. However, even if these aspects were specified, the available modelling tools would very much limit such assessments. Therefore, for future GEOs there's a great need for future GEOs to have both more specified social scenarios, and modelling and other assessment tools will able to deal with these important social dimensions. This will be one of the major issues to be adressed by both the Global Scenario Group and the Modelling Group.

[4] PoleStar is a framework for analyzing economic, resource and environmental information and for examining alternative development scenarios. It is an adaptable accounting system applicable on regional, national, and global scales. Exogenous input activity levels are multiplied by intensity coefficients that specify resources required, pollution emitted, or waste generated per unit of activity.

Box 2.1 *Conventional Development and beyond*

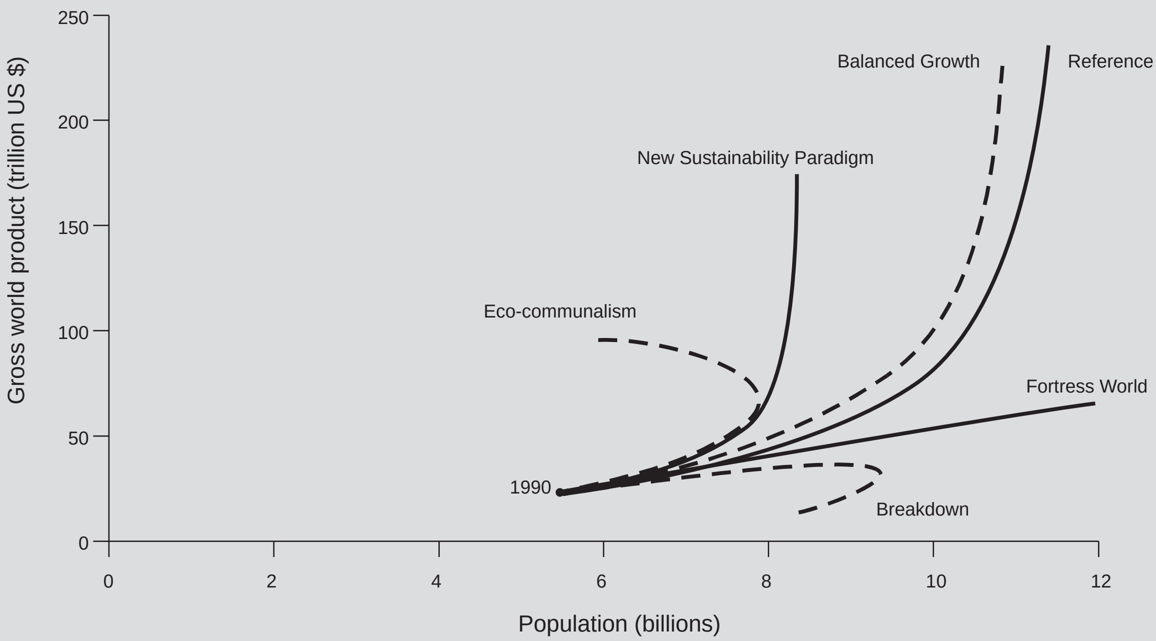

Figure 2.1. *Population and economic growth from 1990-2100 under five development scenarios*
Source: Gallopin *et al*. (1996).

How will the world develop? Clearly, there is no answer to such question. There is no 'most likely' future. Nevertheless, pursuing an equitable and environmentally sustainable development requires the exploration of possible futures and of the options for human choices to help direct the future in an equitable and sustainable direction. For the purpose of the Global Environment Outlook, scenarios would ideally have to meet a number of criteria. They have to be (1) global with sufficient regional disaggregation, (2) comprehensive with integrated treatment of major environmental, social and economic issues, (3) analytically sound with regard to the use of data and scientific theory, and (4) diverse with representation of a range of future visions, values and world views (Gallopin *et al*., 1996). Unfortunately, scenario sets meeting all these criteria are not yet available. Their conception, development, and the sectoral and regional concurrence with their characteristics requires a considerable amount of care, time and effort. For the first GEO, the development and analysis of a set of scenarios meeting the above criteria was proven impossible. Therefore, a Conventional Development scenario was selected that meets the first three criteria to a large extent. The purposes of this approach at this stage were (1) to examine the feasibility of scenario-supported integrated assessment in the GEO context and (2) to explore the potential environmental consequences of a 'business-as-usual' type of scenario with no major policy interventions.

At the same time, UNEP has set up a Global Scenario Group, coordinated by the Stockholm Environment Institute, to start developing alternative scenarios that better meet the four criteria above. Notably, these take into account the different social visions about how the future will or should evolve, and identify key decision aspects how through sustainable development may be furthered through policy intervention. So far, the work of this group has led to the qualitative contours of three classes of scenarios. The central class is a range of 'Conventional Worlds' scenarios, one of which (the 'Reference' or 'Conventional Development' scenario) is analyzed in this report. Noting that from the perspective of sustainable development this is certainly not a desirable type of future, an additional case in this class, called 'Balanced Growth', has been proposed. This scenario assumes heavy and coordinated policy intervention such as called for in the Brundtland report and in many policy-oriented discussions on sustainability. It assumes the political will to implement policy reforms, strengthen management systems, and ensure widespread introduction and use of better technology, with the intention of providing greater social equity and environmental protection than offered by the Reference scenario. Although the Balanced Growth scenario differs from the Reference scenario in its degree of policy interventions, it shares many of the same patterns of production and consumption, notions of global governance, and political and cultural values.

Although most formal scenario and planning exercises confine their analysis to futures that lie within the assumptions of the ‘Conventional Worlds’, many indiviuduals hold much more pessimistic views about human destiny. Consideration of some current global trends suggests that there is a real risk of futures that are incompatible with the notion of progress, growth and expanded human freedom. The Global Scenario Group calls such futures - which might include widespread conflict, breakdown of social order, authoritarian controls, massive human sufferering and irreversible environmental degradation - ‘Barbarization’ scenarios. One variant, ‘Breakdown’, is an extreme case of destructive anarchy where governmental and social failures, unchecked population growth, and environmental and social deterioration lead to scarcity, violence and possible massive migration. These conditions, in turn, eventually lead to widespread economic collapse, a drastic fall in global population levels, and loss of institutions, productive capacity and technological wisdom. Alternatively, the ‘Fortress World’ variant assumes an authoritarian ‘solution’, in which a minority of the elite in privileged enclaves protect their way of life by forcibly imposing limits and social controls on the impoverished majority, by seizing control of critical natural resources for their exclusive use, and by restricting access to information and technology. It is possible that instability of a ‘Fortress’ system may push the world into a ‘Breakdown’ situation.

On the other side of the spectrum, one can hold more optimistic views on how the future may evolve. For several reasons, including a dissatisfaction with the lifestyles, values, equities and environmental conditions offered by the ‘Conventional Worlds’, more radical changes in social goals and practices may emerge, transcending the ‘Conventional Worlds’ framework. The hallmarks of these changes, illustrated in a set of ‘Great Transitions’ scenarios, are new economic and social arrangements, and significant changes in the values that guide individual and collective behaviour. Although such futures may be viewed as utopian and unrealistic deviations from the conventional evolution of society, the hypothesis contrary to this, i.e. that attempting sustainability without such changes is quitoxic, may be entertained. One variant, called ‘Eco-communalism’ represents a deep green utopian vision which emphasizes bio-regionalism, localism, face-to-face democracy, small technology and economic autarky. Population and economic scales diminish, while environmental conditions improve dramatically. Possibly closer to todays’s views on what is feasible, the ‘New Sustainability Paradigm’ variant seeks to alter the character of urban industrial civilization rather than to replace it, to build a more humane and equitable global civilization rather than to retreat into localism. This scenario assumes a dramatic decrease in per capita material flows through behaviorial changes and technology improvements, a resilient and high-quality environment, and high well-distributed welfare with economic activity oriented to services.

The discussion of alternative futures raises a host of profound questions. Which of these pathways are self-consistent and plausible? Can the policy reforms of ‘Balanced Growth’ achieve sustainability, or at least solve the urgent problems in many regions as identified in this report? What critical points could kick the system into global or regional ‘Barbarization’ and what policies and actions are needed to reduce this risk? Can new values and policies transform industrial society as assumed in the ‘New Sustainability Paradigm’? And last but not least, the practical question for next GEOs: what actions are implied?

Source: Gallopin *et al*. (1996).

2.2 Economic activity and population

The past: rapid economic and population growth

The emergence of a global industrial system is a key feature of the evolution of past consumption and production patterns. An essential component of this was the shift from renewable energy sources like biomass, wind and human/animal labour to fossil fuels (coal, then oil and gas). This shift made possible an enormous release of additional energy to support human economic activities, such as industrial production and transportation. It also precipitated a considerable increase in the productivity of agriculture through the use of machines, artificial fertilizers and pesticides. This development, which took place at an unprecedented rate, fundamentally changed the economic relations in the world, as it was combined with colonialism and a struggle by Western industrial states for resources and markets. It marked the early stages of the transition of the economic structure away from dominance by agriculture. While over 50 per cent of the estimated industrial potential (handicrafts as well as industrial manufacturing) in about 1800 was still located in China and India, by 1900 the balance had shifted completely towards Europe and the USA (Bairuch, 1982). In 1900, the world's industrial potential was five times that of the UK; in 1980 it had grown to 110 times that of the UK in 1900, a more than 20-fold increase. Subsequently, a shift towards a rapidly increasing emphasis on the service sector formed the last stage of this transition of the economic structure in the industrialized countries. Rapid institutional developments at various geographical levels facilitated these changes. Major regions of the world have not gone through this process, but are now in the earlier stages of what may yet become a similar economic transition. Because of the different economic, social and environmental conditions in these regions, the transition will in the details be different from that in the currently industrialized countries: the suggested similarity refers to a stylized, aggregate level. Figure 2.2 illustrates the steady growth of world economic output and its acceleration after the Second World War.

Economic growth has brought - and continues to bring - wealth to many, but not to all. The income inequalities of the early days of industrialization have levelled off significantly in most industrialized countries, although inequalities appear to be increasing again in many of them. In many developing countries that are in the early stages of industrialization, however, income differences are still considerable and there is virtually no middle class. There is also still a great deal of income inequality between regions, and this is decreasing very slowly, if at all (e.g. World Bank, 1994).

Global population has continued to increase continuously, showing an acceleration in recent centuries along with economic growth. Braudel (1981) has calculated the world population increase from between 465 million and 545 million in 1650 to between 1530 million and 1608 million in 1900 and, finally, to more than 5600 million now. Population numbers within regions have shown significant fluctuations over time as a function of social, economic and environmental developments[5]. These fluctuations and other historical evidence suggest a dynamic interplay between human populations and their ingenuity, the environment and its food potential, and societal organization. During the last century, a demographic transition towards relatively stable population numbers has taken place in the industrialized countries. And in many developing countries, the process of declining population growth rates has begun, although with varying speeds[6]. With respect to population, it should finally be noted that not only do total numbers change, but also the geographical distributions. Notably, a variety of economic, technological and social factors has resulted in increasing global urbanization.

The future: continued economic growth and decelerating population growth

The assumptions about consumption and production patterns in the Conventional Development scenario are in line with the conventional economic transition concept outlined above. At a stylized level, the implicit paradigm is one of the South copying the production and consumption patterns of the North - with a delay of several decades. Evidently, differences in the economic,

5 This has been well documented for early inhabited regions such as the Tigris-Euphrates Basin, Egypt, China and Mexico, where reconstructed population time-series reflect the rise and decline of civilizations (Whitmore *et al*., 1990).

6 The relationship between the economic and health transitions is much debated. Although there is evidence of a positive relationship between increasing life expectancy, fertility decline and income growth, the complex web of factors that determine demographic development does not justify the conclusion that income growth is a pre-condition for extending life expectancy or decreasing fertility (see also Chapter 6).

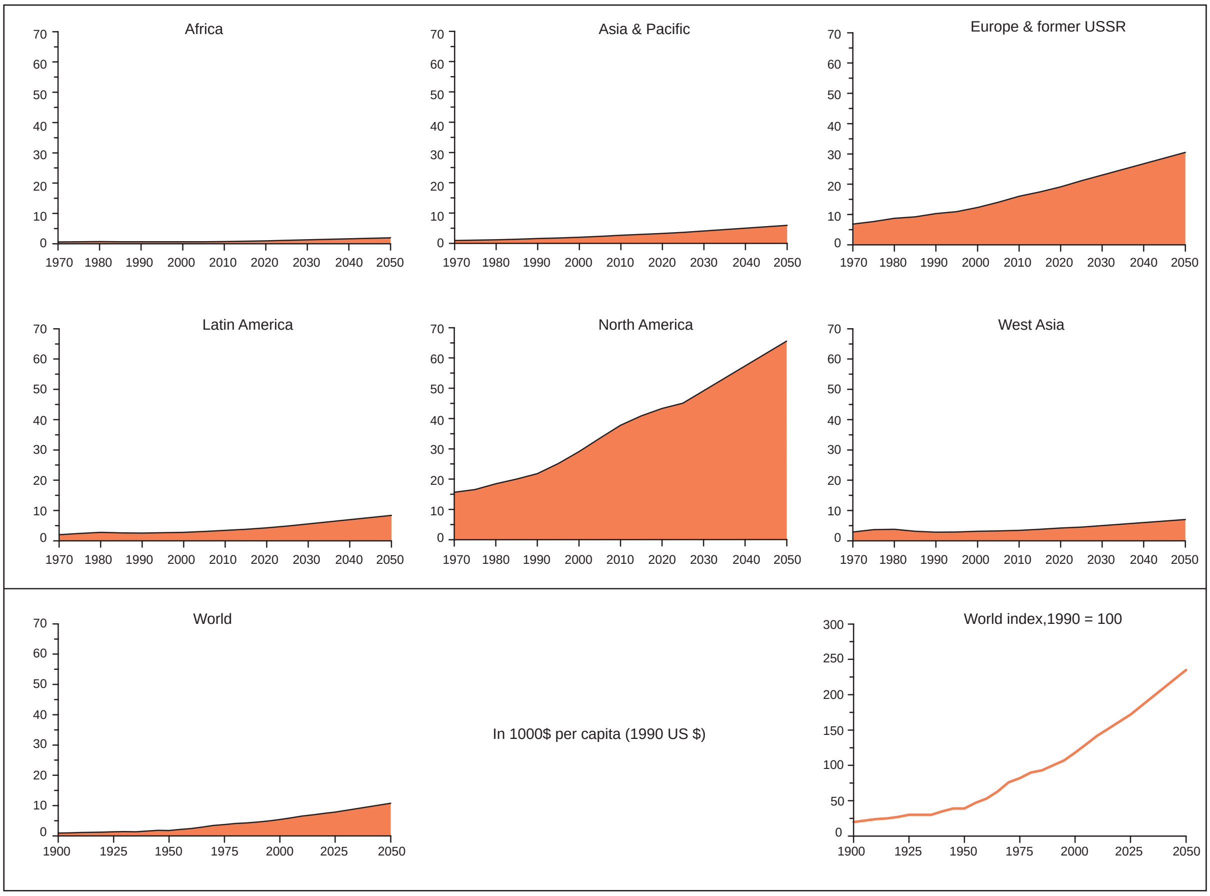

Figure 2.2. *Economic growth in GDP per capita: past growth and future assumptions in the Conventional Development scenario*

Note: The historical GDP calculations depend heavily on the base year taken (here 1990), constant or current prices (here constant) and the currency (here US dollars). The methodology is described in detail in: Klein Goldewijk and Battjes (1995).

Source: Eurostat (1991); IPCC (1992); Kuznets (1971); Maddison (1989, 1994); OECD (1972, 1975, 1975); World Bank (1976, 1990, 1992, 1993).

social and environmental conditions in the regions imply a difference in the detailed characteristics of the transitions. In OECD countries, the service sector typically continues to grow at the expense of the agricultural and industrial contributions to GDP. Non-OECD regions are assumed to converge in the direction of OECD economic structures, with increasing GDP per capita[7]. The GDP assumptions (Figure 2.2) are somewhat lower than historical growth rates but, nevertheless, imply a substantial increase in per capita GDP[8]. It is assumed, for example, that per capita income levels in Latin America and East Asia will exceed current levels in OECD Europe in the second half of the next century. As Table 2.2 shows, per capita incomes in all developing regions are assumed to rise faster than in industrialized countries during the 1990-2050 period,

[7] The economic growth rates are taken from the IPCC IS92a assumptions (Leggett *et al*., 1992) which, –for the short term–are within the range of World Bank projections. In Figure 2.2, the standard economic measure, GDP, has been used. The use of GDP data in this report is assumed to be the most complete and reliable way of measuring production and consumption activities currently available. Nevertheless, this method has several well-known flaws as a measure of welfare, including the limited comparability across country borders due the different price levels in different countries, as well as the failure to take environmental and social 'externalities' into account, while 'defensive' expenditures - counteracting the negative results of these externalities - are included (Raskin *et al*., 1995a).

[8] Note: Historical information for all reported variables in the period 1900-1990 has been drawn from the 'IMAGE 2 Hundred Year (1890-1990) Data Base of the Global Environment (HYDE)' (Klein Goldewijk and Battjes, 1995). Information about the original sources is contained in Appendix I.

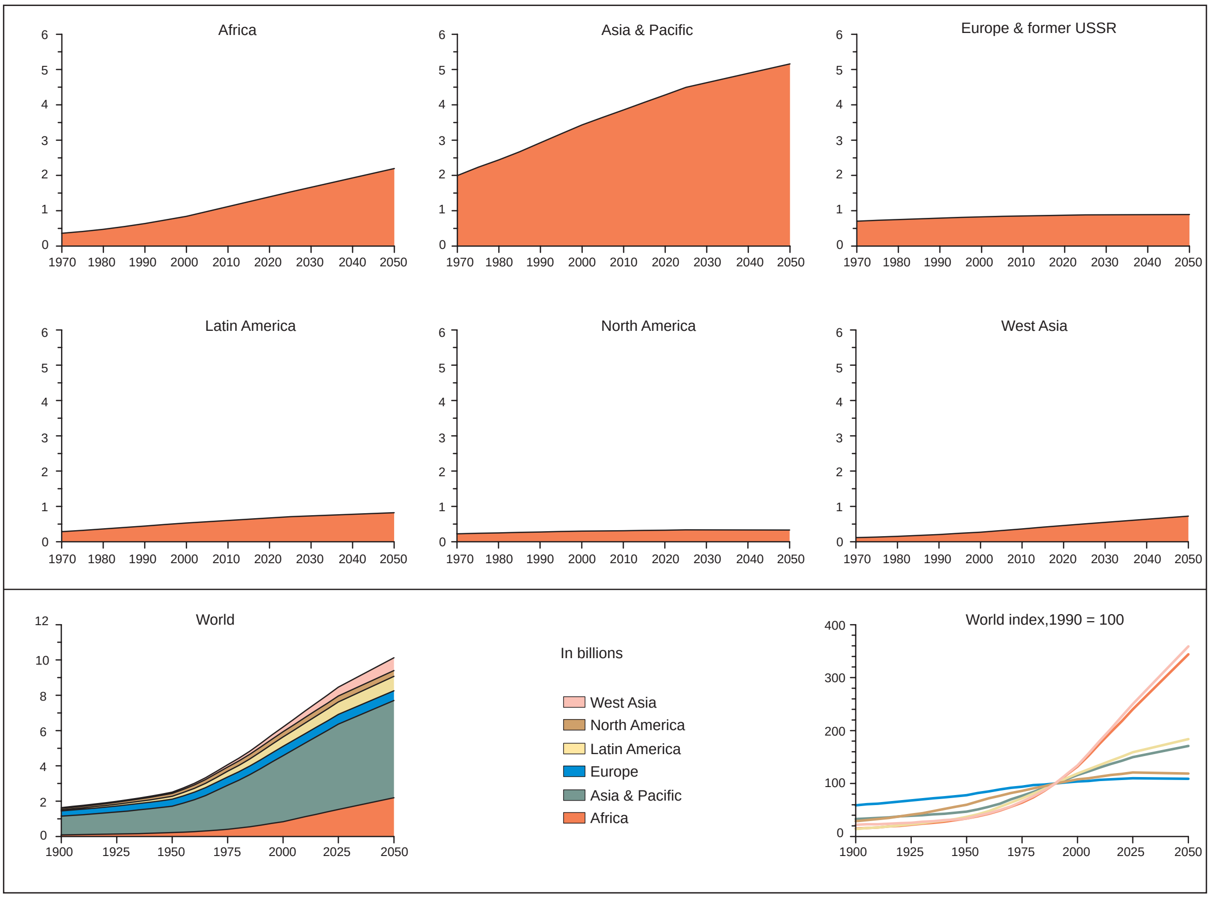

Figure 2.3. *Past population trends and future assumptions according to the Conventional Development scenario*

Note: Data before 1950 calculated by Klein Goldewijk and Battjes (1995) with data from Mitchell (1975, 1982, 1983), data for the period 1950 - 1990 taken from United Nations (1992); after 1990 based on the IS92a scenario (IPCC, 1992).

Source: IPCC (1992); Klein Goldewijk and Battjes (1995); Mitchell (1975, 1982, 1983); United Nations (1992).

with the exception of Africa and West Asia from 1990 to 2015, where per capita income levels do rise, but more slowly, due to such factors as the slower decrease in population growth in these regions. In spite of this, the income gap between developing and industrialized countries is assumed to increase slightly in absolute terms towards 2015 before decreasing slowly towards 2050 (Figure 2.2)[9].

The conventional development paradigm is characterized by increasing economic globalization. It is included implicitly in the scenario through the growth in production volumes, increasing proportions of which are traded. However, whether globalization is a real and persistent trend or not, and if it is, whether the environmental and social consequences are positive or negative, are not explored in this chapter. Neither does the chapter include an assessment of the increasingly free movement of capital and labour implied by globalization.

[9] Total convergence between the per capita income levels in industrialized and developing countries by 2050 - assuming slow 1-1.5 per cent per year GDP growth in the industrialized countries - would necessitate an average of 6 per cent per year growth in developing countries throughout the period. For the poorest region (Africa) to catch up with the richest (North America), a 9 per cent growth rate would be needed. For a 2 per cent growth rate in industrialized countries, these figures would be 7 per cent and 10 per cent, respectively. Please note that such speculation illustrates the income gap, but disregards the positive linkage between economic growth in the industrializing and developing countries and the relationship between population growth and economic development.

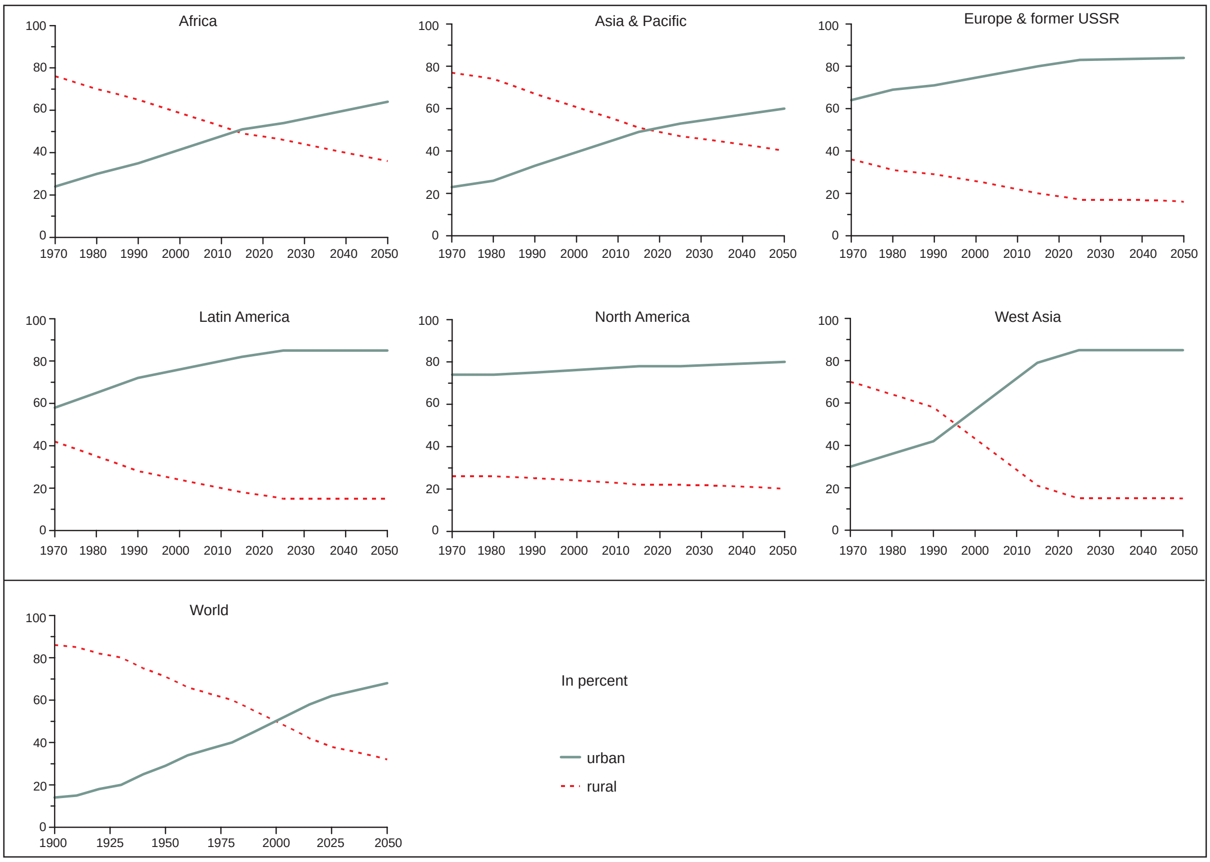

Figure 2.4. *The part of the population living in urban agglomerations: past data and future assumptions according to Conventional Development scenario*
Source: Alcamo (1994); Berry (1990); Klein Goldewijk and Battjes (1995); United Nations (1992); WRI (1986); WRI (1992); WRI (1994).

With respect to population, it is assumed in the Conventional Development scenario that developing countries will experience a demographic transition similar to that which has taken place in the industrialized countries[10].

Figure 2.3 shows the population numbers for the six GEO regions and for the world as a whole. Absolute increments currently exceed 86 million per year and the world population is likely to increase at this rate until 2015. The projected growth in the world population of 4.7 billion, with 95 per cent of the increase in developing countries, produces a total global population of just over 10 billion by the middle of the next century (Raskin *et al*., 1995a). The scenario makes the same demographic assumptions as IPCC, which are consistent with other published scenarios (Alcamo *et al*., 1995) and depend largely on assumed fertility and mortality rates. Despite a decline in birthrates in many countries, large increases in population size are inevitable. However, lower fertility rates would eventually lead to a smaller and significantly older population, while higher fertility rates would lead to a larger and younger population. The difference between the United Nations' high and low population projections for 2015 is 720 million, exceeding the total current population of the African continent (UN, 1994). These estimates do not take into account explicitly the feedbacks of different aspects of development on fertility and mortality determinants. Chapter 6 addresses this issue in more detail.

[10] Demographic projections are taken from the IPCC IS92a scenario (Leggett *et al*., 1992), which derived its assumptions from mid-range United Nations and World Bank estimates (Figure 2.3). The baseline scenario assumes no explicit feedback of environmental changes (including availability or scarcity of water and food) into population dynamics.

Population movements within and between countries, including the very rapid growth of cities and the unbalanced regional population distribution will continue and increase in the future (UN, 1994). Figure 2.4 shows the urbanization assumed in the scenario: by the year 2015, more than 50 per cent of the population in all areas are expected to live in urban conglomerations, as compared to 26 per cent in 1975 in developing regions. The impact of trends in urbanization on the environment has not been specifically specifically in this report.

2.3. Environmental pressures: energy, material use and emissions

The past: the industrial age

Energy consumption in the industrialized regions has increased almost exponentially (Figures 2.5, 2.6) with the growth of population and economies. This, together with a similar rise in minerals used in the production of metals (Figure 2.7), fertilizers (Figure 2.8) and construction materials, has led to sharp increases in the emissions of pollutants into all environmental compartments, including emissions to air (Figure 2.10) and water, and waste. As the figures illustrate, the causes of environmental pressure do not have equal distribution. Notably, the consumption of energy, but also of fertilizer, has been concentrated disproportional in the industrialized countries. In terms of production (e.g. fuels and metals, as illustrated in the figures) the developing countries are more important in that to a large extent they are needed to export to the industrialized countries. One can discern in the graphs the rapid rise in production after the Second World War which followed dips in the economic crisis years of the thirties.

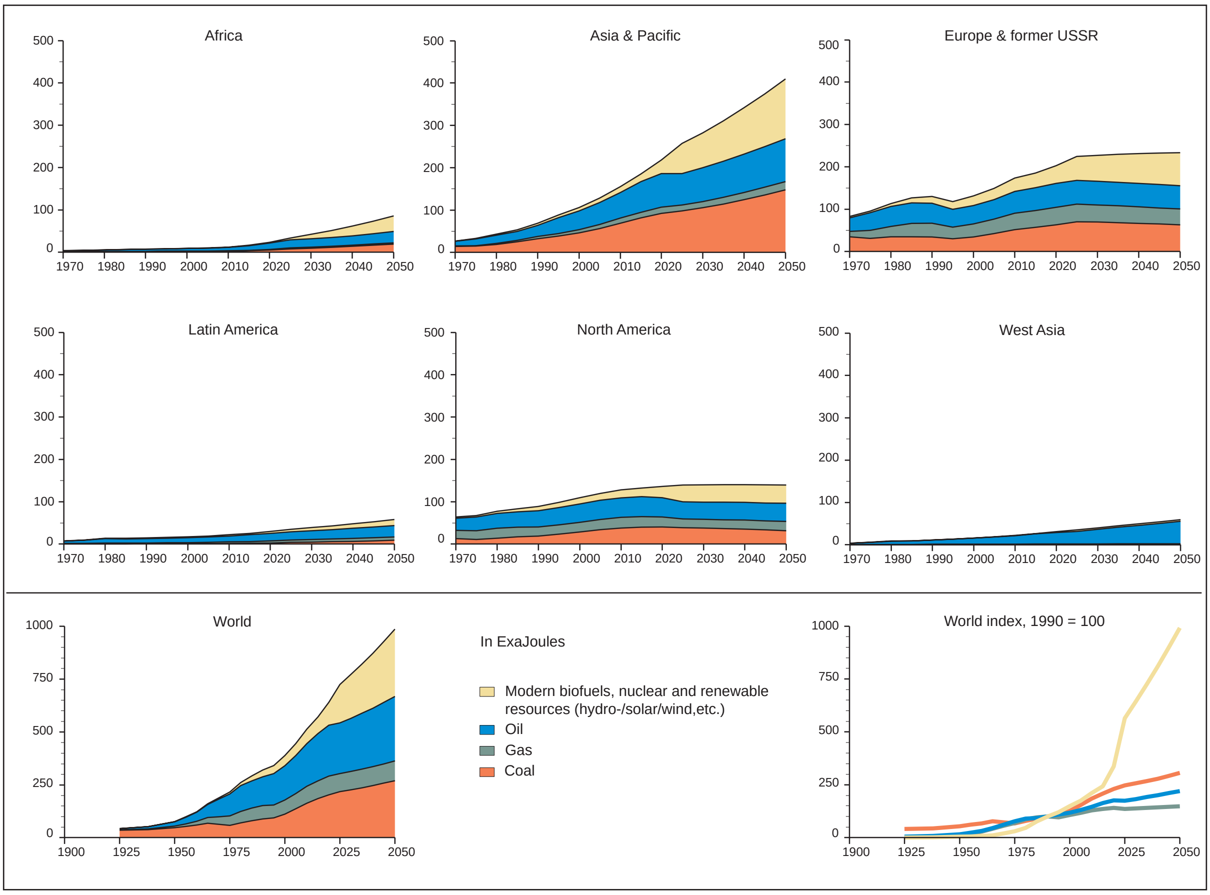

Figure 2.5. *Past primary energy consumption and future assumptions*
Note: Including modern biofuels. This is different from the overview tables 2.1 and 2.2.
Source: Historical data until 1965: Darmstadter (1971); other data and projections: Alcamo and Kreileman (1996);

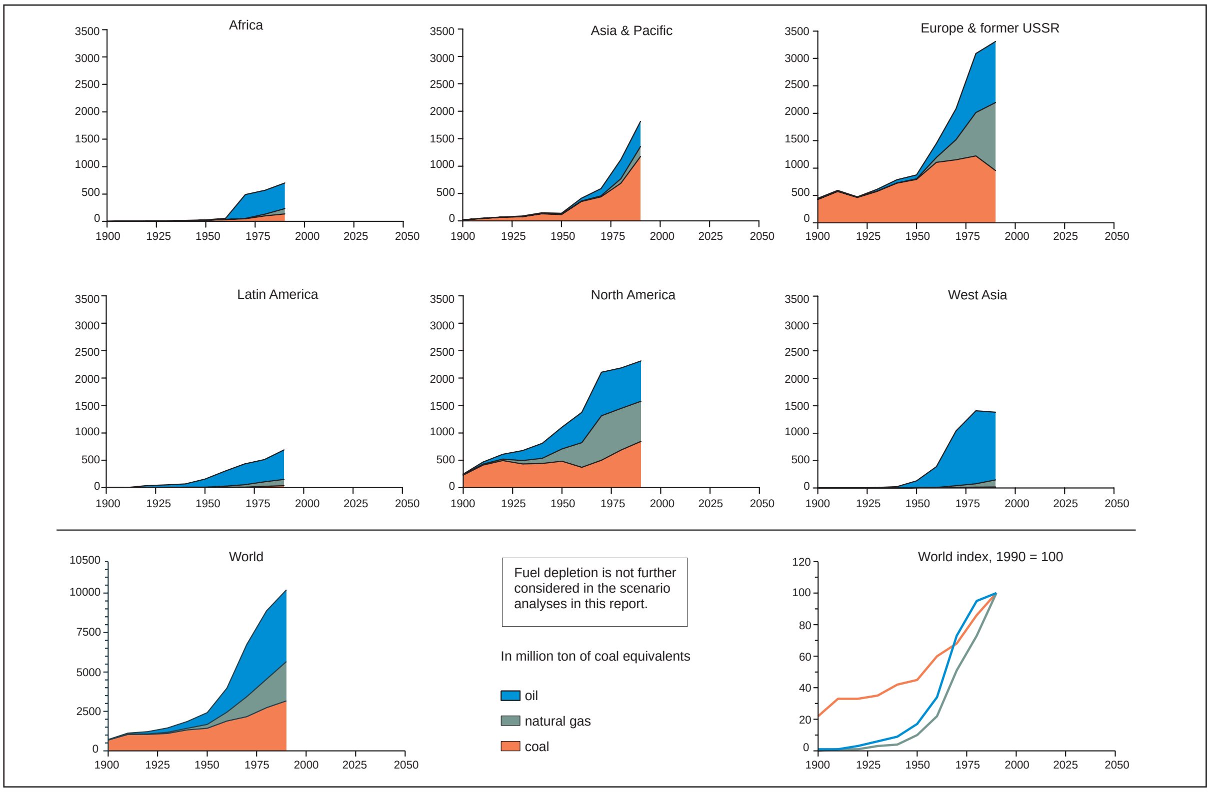

Figure 2.6. *Production of fossil fuels up to 1990*
Etemad et al (1991); WRI (1994); Klein Goldewijk and Battjes (1995).

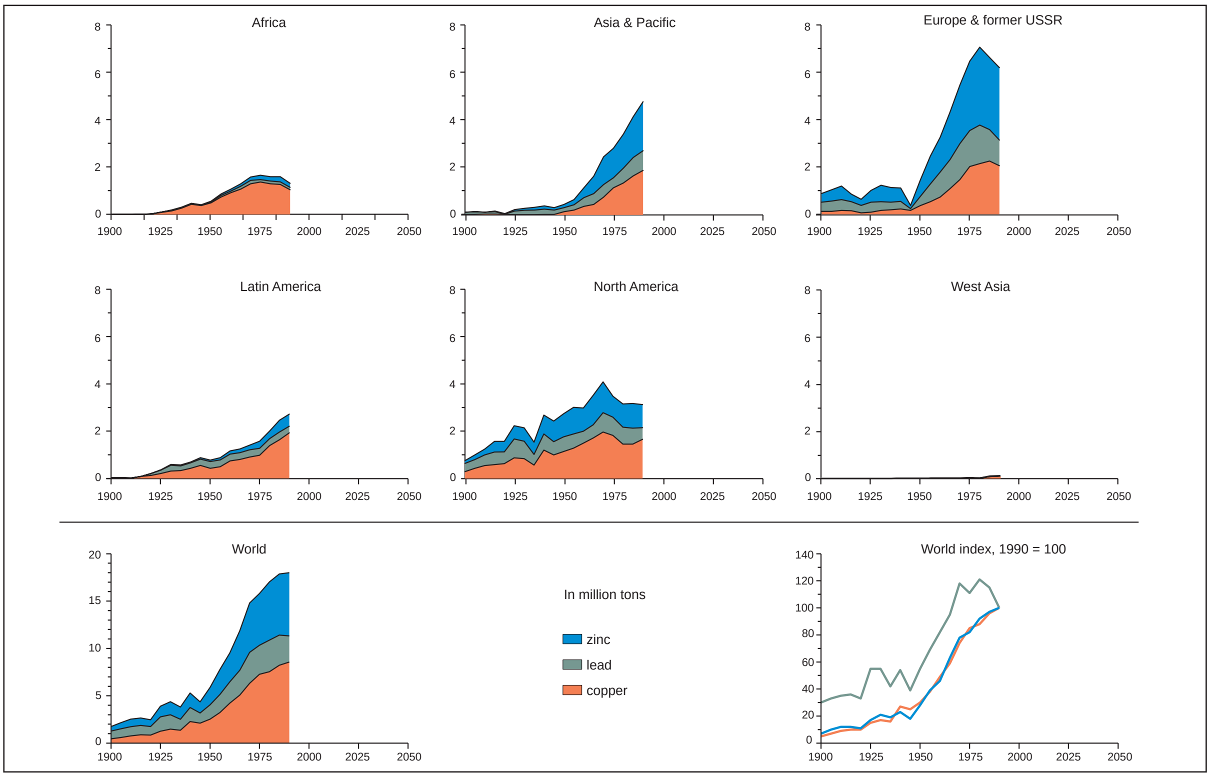

Figure 2.7. *Production of selected metals up to 1990*
Note: Data refer to smelter production.
Source: Klein Goldewijk and Battjes (1995); Metallgesellschaft (1971, 1981, 1991, 1992); Schmitz (1979); Woytinsky and Woytinsky (1953).

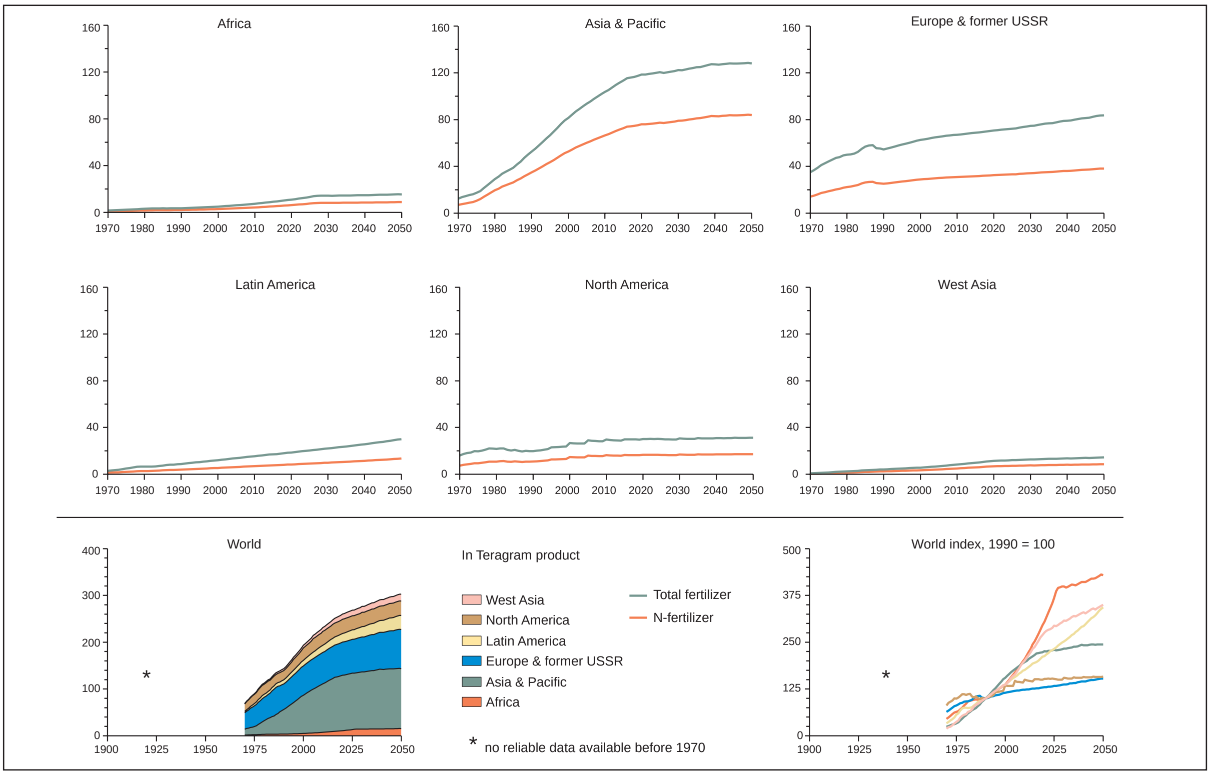

Figure 2.8. *Past fertilizer consumption and projections following the Conventional Development scenario*
Note: Historical data (before 1961; the start of FAO's AGROSTAT data base) on fertilizer use are hardly available on a country basis, but since chemical fertilizers were not widely used before 1950, the lack of information is considered acceptable.
Source: Until 1990: FAO (1990); later and projections: Alcamo (1994).

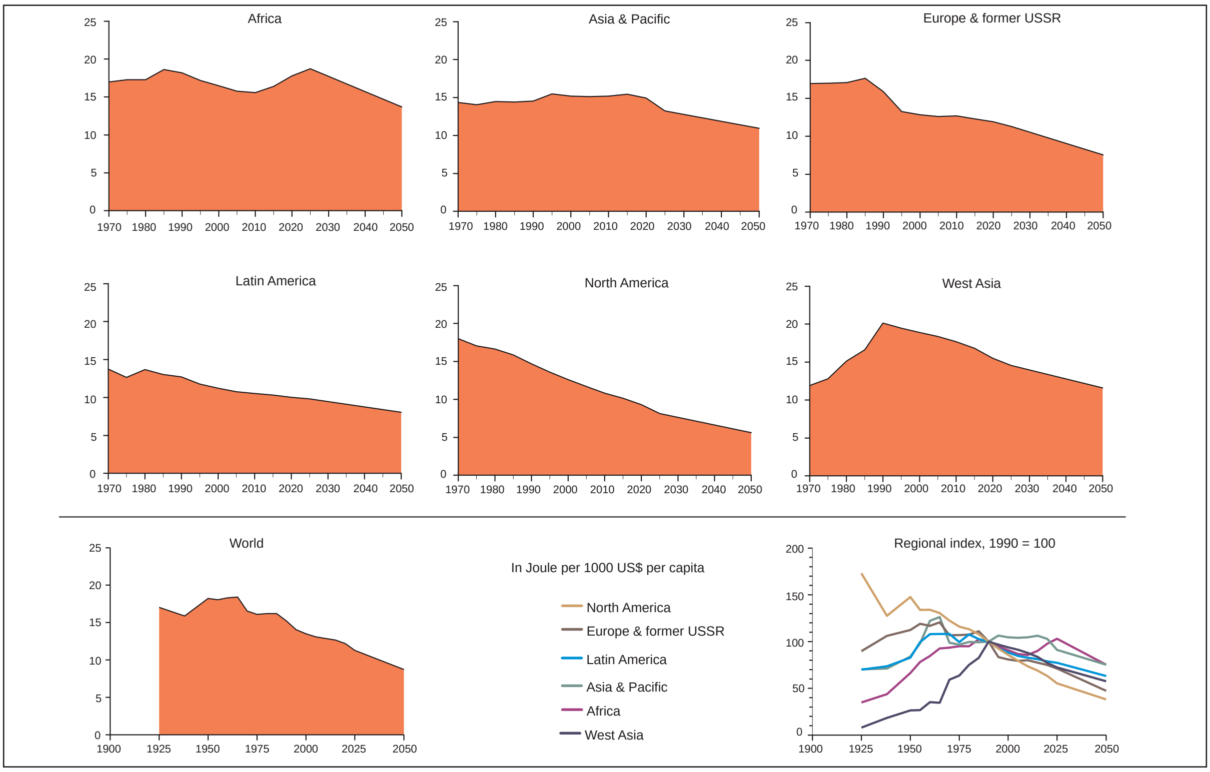

Figure 2.9. *Past energy intensity of economies and projections following the Conventional Development scenario*
Note: Energy intensity is defined as Primary Energy Consumption/Gross Domestic Product. Exclusive of modern biofuels.
Source: Alcamo (1994).

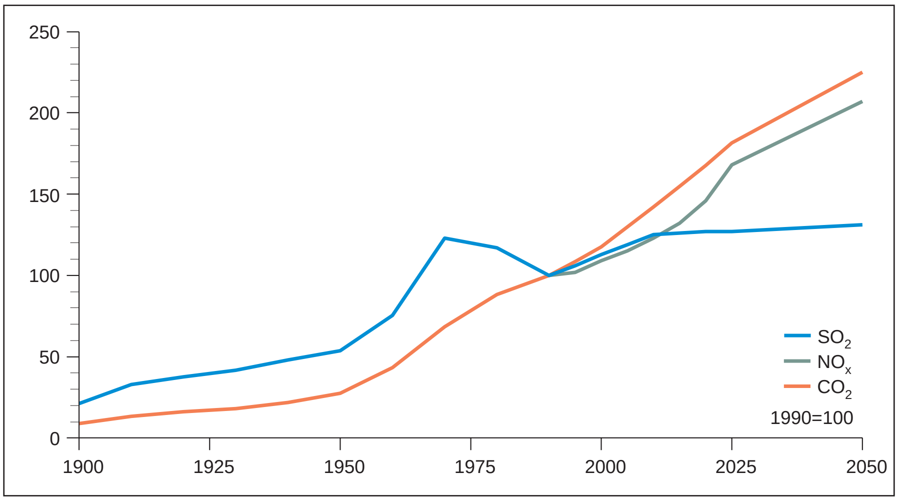

Figure 2.10. *Index of global emissions of sulphur dioxide, nitrogen oxides and carbon dioxide following the assumptions of the Conventional Development scenario*

Source: Historical data: Alcamo and Kreileman (1996); Gschwandtner *et al*. (1985); Hameed and Dignon (1988); Keeling (1973, 1994); Klein Goldewijk and Battjes (1995); Marland and Rotty (1984); Marland *et al*. (1994); Mylona (1993); Overrein et al. (1981); Placet and Streets (1987); WRI (1994). Data for carbon dioxide emissions before 1990 are derived from Keeling (1994); data after 1990 are assumed and are from Posch *et al*. (1996).

It is only in the last 10 to 20 years that signs of a decoupling between economic activity and the use of energy and materials have appeared. Concerns about human health, and later on, also about the natural environment have induced the industrialized countries to develop and enforce environmental regulations to curb the level of emissions. Initially, they lowered the concentration levels by ‘dilution’ (e.g. high chimneys), followed later by so-called end-of-pipe technologies, preventing pollutants from entering the environment. Recently, this happened more and more by using cleaner and more efficient production technologies. Figure 2.10 shows that as a consequence, global emissions of sulphur compounds have more or less stabilized but the emissions of carbon dioxide and nitrogen oxides continue to increase. Notwithstanding efficiency improvements and environmental measures, the growth of levels of activities in industry, transport, households, services and agriculture has, in general, led to increasing environmental pressures[11].

Decoupling between resource consumption and economic growth has been demonstrated in production in industrialized counties and is to a large extent linked to the above-mentioned economic transition: during the early stages of industrialization energy-intensive heavy industry is needed for building infrastructure, production capacity and constructing buildings. Later on there is more need for light industries and services to meet consumer demand and improve economic efficiency. An unknown part of this so-called ‘dematerialization’ of the industrialized economies has been due to a shift of energy-intensive basic processing to less-developed countries. Also, the oil prices hikes of 1973 and 1979-1980 have given a temporary stimulus to increase the efficiency of energy and materials (Figure 2.9).

[11] Pre-industrial inputs of acidifying substances such as *sulphur oxides* to the land surface have more than quadrupled as a result of atmospheric deposition and fertilizer use (Figure 2.8). Deforestation and the extensive use of fossil fuels since the industrial revolution have resulted in a large increase in anthropogenic emissions of *greenhouse gases* like carbon dioxide (Figure 2.9), nitrous oxide and methane, accompanied by an increase of greenhouse gas concentrations in the atmosphere. And, until two decades ago, the increasing release of *toxic and persistent chemicals* led to increasing concentrations of these substances in air, water and soils. In the industrialized countries, cleaner production processes and the application of less toxic substitutes, often induced by government regulation, has led to decreasing concentrations of many of the most toxic substances in recent years.

It should be noted that recent analyses of longer trends in the achievements of environmental policy in the Netherlands indicated that environmental gains from ‘dematerialization’ tends to be limited to certain issues in the production sector and traffic, and can eventually be eroded by volume growth (‘recoupling’).

The future: the use of energy and raw materials continues to increase and the level of emissions remains largely unabated

In the Conventional Development scenario, energy demand grows significantly globally and throughout all regions (Raskin and Margolis, 1995). Notably the economic development in industrializing countries requires a spectacular increase in energy consumption (a factor of 5 or more between the present and 2050 in Africa, West Asia/the Middle East and Asia). This is notwithstanding the scenario assumption that the energy intensity of economies will decline in all regions. In the Conventional Development paradigm, this demand is expected to continue to be met primarily by still abundant and versatile fossil fuels. Figures 2.5 and 2.6 show key energy aspects of the scenario, which assumes that development is not constrained by the limited availability of energy resources[12].

In the scenario as interpreted for the present analysis, the increased use of fossil energy and other mineral resources is accompanied by emissions of various kinds, including acidifying substances, nutrients, greenhouse gases, toxic substances and waste. As noted above, emissions of selected pollutants per unit of activity have eventually declined in industrialized countries as part of the economic transition in industrialized societies. For example, as described in Chapter 3, emission factors of sulphur oxides in developing regions have been assumed to develop - under assumed policy reactions to rising pollution levels - considerably towards what is now common in industrialized regions. Thus, increased efficiency and substitution or specific control technologies may lead to lower emissions than is assumed in the scenario. However, this relationship has only been found to be true for a limited number of local and regional pollutants in a limited context. It is uncertain whether the relationship would also hold for emissions of substances that affect global cycles (such as greenhouse gases), or if it would also apply in developing countries that do not have the option to ‘export’ their environmental pressures.

A particularly uncertain factor is to what extent the development and implementation of clean technologies, methods and processes in industrialized countries will spill over or be transferred to developing economies. Chapter 7 will return to these crucial issues. As illustrated in Figure 2.10, the growth in the developing countries’ economies outweighs the decrease or stabilization of emissions in industrialized countries at the global level. Not only do global carbon dioxide emissions continue to move upwards, but the declining trend in emissions of sulphur and nitrogen[13] compounds is also reversed in the scenario.

[12] As Raskin and Margolis (1995) argue, this may be an optimistic view, since it is uncertain whether the required investments can be made and existing economic, environmental and social constraints for different fuel types can be overcome. Given the economic and population estimates, the energy picture is primarily characterized by the energy intensity of the economy and the fuel mix. Comparing the scenario with other published energy scenario, the IPCC IS92a case (the basis for the Conventional Development scenario) is a typical mid-range scenario at the global level, which does not imply that it is a likely scenario. At the regional level, Alcamo *et al*. (1995) identified some discrepancies with other published cases, mostly caused by differences in assumptions on economic growth (e.g. in the former USSR and Eastern Europe). It is important to note that the range of published energy scenarios up to 2050 is significantly smaller than beyond 2050. There is a large contrast, for example, between the IS92a scenario, where the reliance on fossil fuels continues after 2050, and a recently published scenario by Kassler (1994), where a shift towards renewable energy takes place around 2050. This is driven primarily by autonomous technological innovation, leading to a qualitatively different energy system in the second half of the next century and with very different environmental implications. The Conventional Development scenario is very similar to the High Growth case in WEC (1993) and the mean High Growth case in a set of recent scenarios from IIASA/WEC (WEC, 1995). In the IIASA/WEC scenarios rapid economic growth can also lead to higher or lower emissions of carbon dioxide, depending on the availabiltiy of the different fuels in the next century. Slower economic growth does not automatically lead to lower emissions of carbon dioxide because of a reliance on cheap coal reserves (WEC, 1995).

[13] For nitrogen oxides, the rapid growth of private transport worldwide is another important factor.

2.4 Environmental pressures: demand for land and water

The past: vastly improved supplies of water and food

From a historical perspective, the nutritional levels of the world population have until recently been on average relatively low and food has not been distributed very evenly. Hunger and malnutrition have been more the rule than the exception during much of human history. In recent decades, significant improvements in global nutritional levels have been achieved in most regions. Unfortunately, there are important exceptions, notably in parts of Africa and South Asia. What determines nutritional levels? In addition to population pressures, income levels and associated dietary habits determine the demand for quantities and types of food. With higher incomes, caloric intake generally increases and there is a shift towards including secondary foods, notably meat and dairy products (see Figure 2.11).

Increased agricultural productivity and trade, and enhanced storage facilities, have improved food security in most regions by increasing supply. Doomsday prophets have often predicted that the food supply would not be sufficient to keep pace with population growth. So far, human ingenuity has time and again proved these voices wrong, for example, in the sixties and seventies with the Green Revolution. Notwithstanding some negative side-effects, this revolution has increased food security for millions of people. The expansion of agricultural production has been one of the key reasons for increasing withdrawals of freshwater (irrigation), alongside water withdrawals for domestic and industrial use. Figure 2.12 shows the development of regional water withdrawals. However, this does not imply that food problems could not occur in the future.

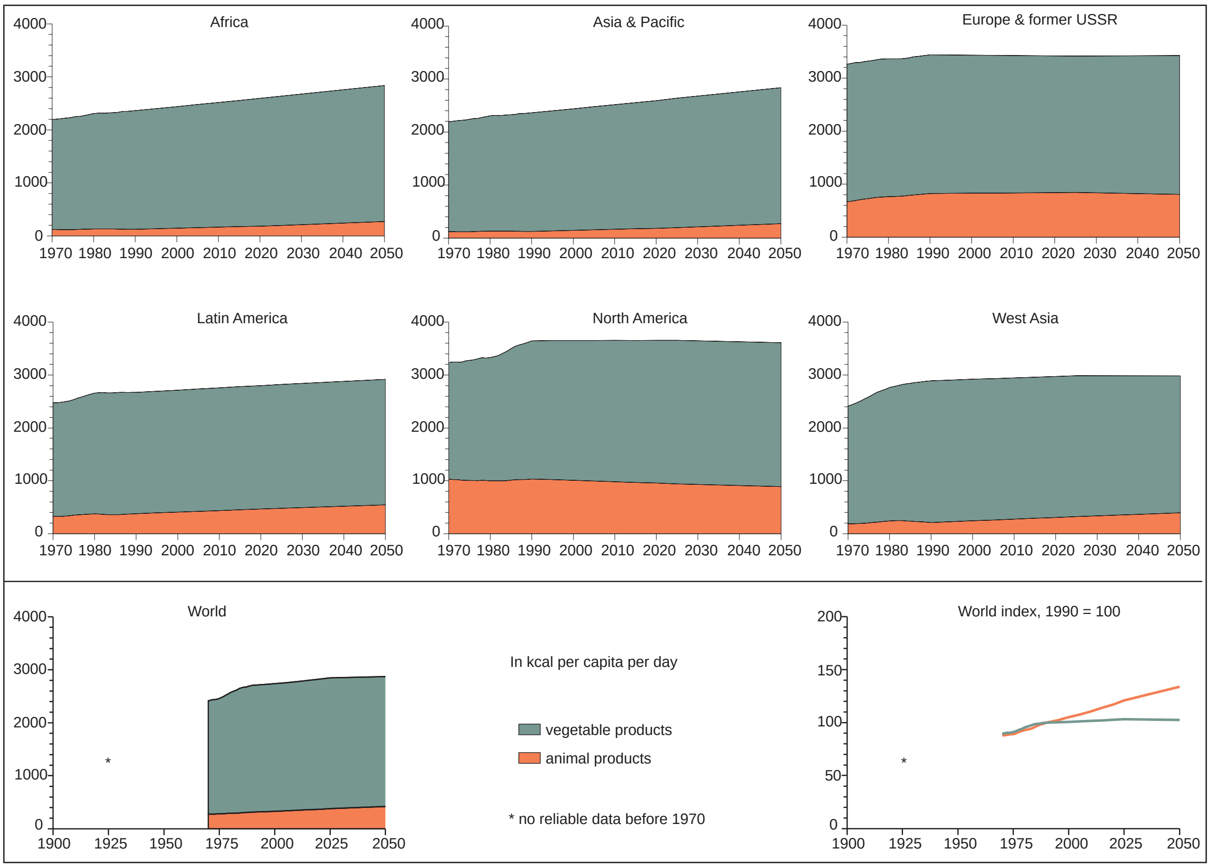

***Figure 2.11.** Caloric intake, projections following the Conventional Development scenario*

Note: Caloric intake is the total of Vegetable products (temperate cereals, rice, maize, tropical cereals, roots and tubers, pulses, oil crops, others) and Animal products (meat from cattle, meat from pigs, meat from sheep and goats, meat and eggs from poultry, milk from cattle).

Source: Alcamo and Kreileman (1996).

The future: increasing demand for land, food and water met

The Conventional Development scenario (Leach, 1995) assumes that taking the global average nutrition will continue to improve and thus that, in general, environmental and economic constraints will be overcome[14]. Figure 2.11 depicts the assumptions with respect to caloric intake in the Conventional Development scenario, assuming a convergence towards OECD dietary patterns. Due to low - although increasing - income levels and high population growth, this development is slowest in Africa. While the proportion of animal products in the diet is assumed to remain relatively stable at around 30 per cent in industrialized countries, it is assumed to increase from 10 per cent in 1990 to 15 per cent in 2015 to 17 per cent in 2050 in developing countries. The required additional production will have to be come from a combination of intensification (primarily increasing inputs), expansion (land conversion) or imports. Chapter 4 discusses what this may imply for global and regional land use. Box 2.2 provides two calculation examples, for energy and agricultural production, in terms of global averages. As to water, because of increases in efficiency and a shift to less water-intensive activities, global freshwater demands are assumed to increase at a much slower rate than economic output (by a factor of just over 1.5 over the whole period) from about 3000 km^3 today to 4000 km^3 in 2025 and 4600 km^3 in 2050 (Raskin *et al.*, 1995b). On a per capita basis, withdrawals in the period 1990-2015 are actually projected to decrease in many

***Box 2.2** Increases in efficiency and increases in demand: the remaining challenge*

The two examples in this box illustrate the increases in efficiencies assumed in the Conventional Development scenario, as well as the remaining challenge when the absolute growth in demand is taken into consideration. The data used in the examples are world totals, taken from the summary of Chapter 4 (the increases in agricultural area) and Table 2.1 (all other data).

Increase in energy efficiency

Energy efficiency is defined here as units of Gross Domestic Product per unit of Primary Energy consumed.

	Primary Energy Consumption (A)	GDP (B)	Energy Efficiency (B/A)	Indexed Energy Consumption	Indexed Energy Efficiency
	EJ	Trillion $	Trillion $/EJ	1990=1	1990=1
1990	321	21.0	0.07		
2015	571	45.1	0.08	**1.8**	**1.2**
2050	837	96.0	0.11	**2.6**	**1.8**

Increase in agricultural efficiency

Agricultural efficiency is approximated here as global caloric intake (as a proxy for agricultural yield) divided by the agricultural area.

	Indexed Area (A)	Caloric Intake (B)	Indexed Caloric Intake (C)	Agricultural Efficiency (C/A)
	1990=1	trillion kcal/day	1990=1	1990=1
1990		14.3		
2015	1.27	21.1	**1.5**	**1.2**
2050	1.42	29.1	**2.0**	**1.4**

[14] Because this chapter focuses on land use, fish products have not been analyzed in detail. While fish only contributes approximately 1 per cent to global dietary calories it is an important source of fat and proteins in some cultures (Raskin *et al.*, 1995).

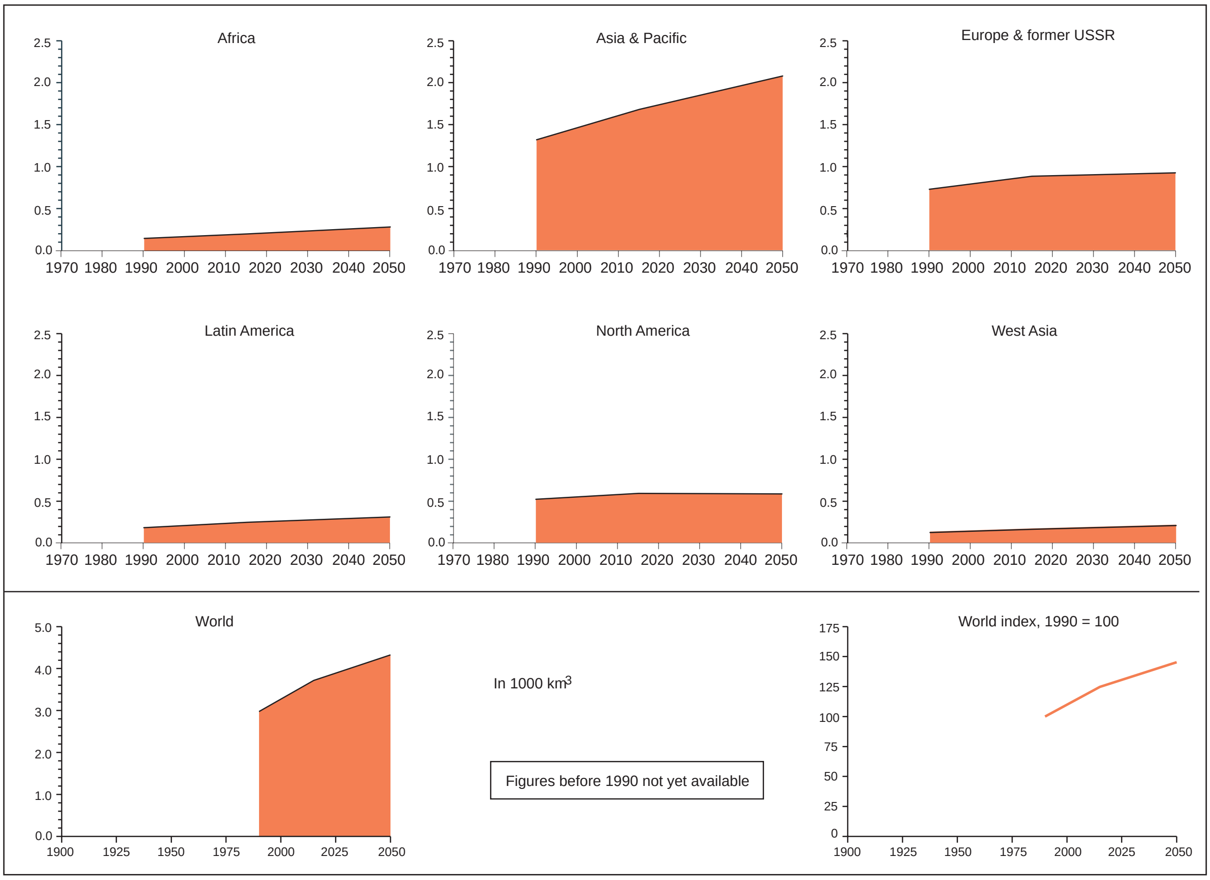

Figure 2.12. *Projected water withdrawals following the assumptions of the Conventional Development scenario*
Source: Raskin *et al.* (1995).

regions, notably in Africa and West Asia. The reason for this is that although withdrawals for domestic and industrial purposes are assumed to increase, this is not equally the case in withdrawals for agriculture. At the same time, under the assumptions of the scenario irrigation only increases marginally and production increases are mainly generated by rain-fed agriculture (see also chapter 4).

Figure 2.12 shows the projected withdrawals by region for the domestic, agricultural and industrial sectors. Similar to the other scenario assumptions discussed, the most important increases are assumed to take place in the most rapidly developing areas, notably in Asia, while in the industrialized countries demand levels off (Europe) or even decreases (USA). As to the availability of clean drinking water and sanitation, it is assumed that global levels will converge towards OECD levels[15].

2.5 The goals: Agenda 21 and the Conventional Development scenario

Although the emphasis in this Global Environmental Outlook is on the environmental consequences of social and economic developments, it is useful to compare the characteristics of

[15] As in the land and food assumptions, current patterns of water supply - in regions such as North Africa and West Asia - may not warrant the optimism inferred by the scenario that increasing water demands will be increasingly satisfied. Clearly, this will not happen by itself but requires that the benefits of the assumed economic growth be tapped for the promotion of sustainable land and water management practices. It should be borne in mind that the analysis in this report is a ‘what-if’ analysis.

the Conventional Development scenario with the broad socioeconomic objectives of Agenda 21. Agenda 21 articulated broad goals relating to the socioeconomic driving forces and the associated environmental pressures. Out of many issues in the Conventional Development scenario, the focus in this chapter is on production and consumption patterns, population growth, derived demand for energy and raw materials, and derived demand for food and water. With respect to consumption and production patterns, the key issue in the Rio Declaration is the need to eradicate poverty, decrease disparities in living standards and thus meet basic human needs. Appropriate patterns of production need to be promoted to reduce environmental stress.

On population, the International Conference on Population and Development stipulated as one of its objectives ‘to facilitate the demographic transition as soon as possible in countries where there is an imbalance between economic and environmental goals’ (UN, 1994). Countries should aim at a life expectancy at birth in 2005 of 70 years or more and by 2015 75 years or more. In countries with current high levels of mortality this should be 65 and 70. Also, countries should strive to reduce their infant mortality rates to below 35 per 1000 live births by the year 2015 and an ‘under-five’ mortality rate to below 45 per 1000 (UN, 1994). The 1995 Social Summit in Copenhagen reiterated and elaborated the social aspects of development (UN, 1995). The use of energy and raw materials is not dealt with as a separate chapter in Agenda 21, nor are there any other formal international policy initiatives which comprehensively address this issue - that is at the root of many of the environmental pressures discussed in this report. In Agenda 21, the development and implementation of environmentally sound and cost-effective energy systems - particularly new and renewable ones - is called for, primarily to reduce the adverse effects on the atmosphere. For the same reason, Agenda 21 calls for an increase in efficiency in the production and consumption of all resources and materials by industry, by improving pollution abatement technologies and by developing new environmentally sound technologies. As far as land is concerned, Agenda 21 refers to the need for food security and, where appropriate, food self-sufficiency within the context of sustainable agriculture, as well as the requirement to eradicate hunger. As far as water is concerned, Agenda 21 emphasizes the need to provide, on a sustainable basis, access to water in sufficient quantities as well as proper sanitation for all, with the emphasis on ‘some for all rather than more for some’.

2.6 Are the goals considered potentially achievable?

In this scenario the world of poverty continues to exist alongside a world that is, on average, richer and healthier. While it is expected that the relative income gap will be reduced in the next few decades (the scenario period), the absolute gap between the rich and the poor continues to widen in the first decades and therefore the goals of increasing international equity are not met. In the scenario, decreasing fertility and mortality rates are assumed to lead to the stabilization of the world population by the end of the next century. The targets for increases in life expectancy and decreases in infant mortality are broadly in line with the Cairo objectives. As to energy and raw materials, the scenario assumes significant technological developments such as the more effective use of scarce materials and increased energy efficiency. In the scenario, the use of energy and raw materials continues to diminish relative to production volumes, but does not stop or reverse current pressures on the natural resource base because gains in efficiency are outweighed by economic growth in absolute terms. This happens, notably, in particular regions (the developing countries) and sectors (e.g. the energy and transport sectors). Finally, as to food and water, food security and self-sufficiency are enhanced, albeit with regional exceptions, and water availability is improved. However, as will be discussed in more detail in the following chapters, these are input assumptions about what may happen rather than actual projections of what will happen.

The following chapters will attempt to analyze how these developments in driving forces and associated pressures may affect such environmental issues as the quality and quantity of land and freshwater resources, acidification and climate change. The final chapter (chapter 7) will evaluate the outcome of the scenario analysis and briefly explore policy options.

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3 INTERACTIONS BETWEEN LAND, WATER AND THE ATMOSPHERE

3.1 The issue

The previous chapter described the relentless growth of consumption and production, population and the associated demand for energy, materials, food and water - as assumed in the Conventional Development scenario. These developments have far-reaching political consequences since they hinge on important matters such as equity, poverty, international security, trade and consumption patterns. They also have a significant impact on the interactions between the atmosphere, land and water. There is an important set of issues emerging from this impact. These issues, which pose a special challenge to the international community because they include so many different complex processes spanning different parts of the natural environment over long periods of time, will have an important effect on the feasibility of many action points in Agenda 21. Moreover, their scope is so vast that they can be viewed as disruptions of large-scale biogeochemical cycles (see Box 3.1). This chapter of the report focuses on some of these key issues, notably in the areas of climate change, acidification and their interactions. While these represent only a subset of issues relating to the interactions of atmosphere, land and water, they are given special attention here because they illustrate the importance of the strong interlinkages between environmental problems, of the inertia of socioeconomic and environmental systems, and of the feedbacks between these systems. They are closely related to the unsustainable use of energy and materials - the root cause of many environmental problems - and they impact on land resources, the associated availability of food, biodiversity and even health.

3.2 The main causes of acidification and climate change: energy consumption, industry and deforestation

In a general sense, the issues discussed in this chapter - acidification and climate change - have the same root cause, namely a high level of economic activity that results in huge amounts of substances being emitted into the atmosphere. Moreover, many of these stem from the same source - the burning of fossil fuels. This accounts for over 80% of the global emissions (in 1990) of carbon dioxide (IPCC, 1992), the main greenhouse gases, and about 94% of the European emissions (in 1990) of sulphur dioxide, the main cause of the acidification of Europe's environment (EEA, 1994). As shown in Chapter 2, the past and current consumption of energy, and the associated emissions, are concentrated in the industrialized countries. In contrast with the emissions of some other pollutants - such as sulphur dioxide and particulate matter - emissions of greenhouse gases have not been demonstrated to decrease with increasing income levels. It has been assumed therefore that they continue to grow rapidly in the scenario, predominantly in the developing regions. Also, notwithstanding important technological advances in the design of motor-car engines, the growth in the volume of the transport sector contributes to projected growing emissions of nitrogen oxides, which are important acidifying substances. Another common source of both acidifying and greenhouse gases is the manufacture of industrial products. An unwelcome by-product of some manufacturing processes is the release into the atmosphere of sulphur dioxide, nitrous oxides, carbon dioxide, halocarbons and other acidifying and greenhouse gases.

While fossil fuels and industrial production account for the majority of emissions of polluting and greenhouse gases, agricultural activity is also an important source of emissions. As an example, agricultural expansion in the tropics often leads to forest clearance and the burning of trees and

Box 3.1 *Disruption of Biogeochemical Cycles*

A useful way to think about the problems presented in this chapter is to consider them as disruptions of biogeochemical cycles. Such cycles are the natural pathways of elements through the earth's atmosphere, land, water and biosphere. When these pathways are disrupted by human activity, a variety of negative environmental consequences usually occur.

Acidification of the environment, for example, can be thought of as the disruption of the natural regional-scale cycle of sulphur and nitrogen (see also Galloway, 1995). Even in the absence of human influences, a certain amount of sulphur is emitted into the atmosphere from volcanoes, from bacteria in the seas and from other natural sources. This sulphur is later deposited onto soils and water bodies in quantities large enough to be beneficial to plants as a micro-nutrient, but small enough to be absorbed by soil and water without any acidifying effects. Eventually most of the sulphur passes harmlessly into the ocean. (Sometimes, however, even natural levels of sulphur deposition can be fatal to plant and animal life, as in the case of sulphur deposited in the vicinity of a volcano during an eruption). The natural sulphur cycle is disrupted when fuels containing sulphur are burnt, contaminating the atmosphere with levels of sulphur far in excess of natural levels. This leads to deposition rates of sulphur that are much higher than natural rates, and eventually to the acidification of soils and waters. The nitrogen cycle is also increasingly being disturbed by human activities in the fields of energy use, transport, industry and agriculture. The nitrogen cycle plays a role not only in climate change and acidification, but also in ozone depletion and the changing oxidation capacity of the troposphere and eutrophication. Increasing amounts of phosphorus are being mined and brought into the biosphere as fertilizer, contributing to problems such as the eutrophication of fresh and coastal water resources. The nitrogen and phosphorus cycles are closely intertwined with those of sulphur and carbon in ways that are not fully understood and quantified but they are not dealt with in this chapter.

In a similar way, climate change can be thought of as the result of disruption of the natural global element cycles, notably that of carbon. Under natural conditions, huge amounts of carbon are exchanged between the earth's atmosphere, land and water. Despite the scale of these exchanges, they have remained fairly constant over many centuries because of natural feedback controls in the earth's system. This situation changed after the industrial revolution, when larger and larger quantities of carbon were emitted into the atmosphere as a result of activities such as the burning of fossil fuels, industrial production and the clearing of forests. The emissions of carbon dioxide and other gases from human activity have disrupted the natural exchange of carbon between the earth's atmosphere, land and water, resulting in the rapid build-up of carbon dioxide and other greenhouse gases in the atmosphere. This build-up contributes, in turn, to climate change.

underbrush, which together release large amounts of carbon dioxide and other greenhouse gases into the atmosphere. Other examples of agricultural sources of greenhouse gases are methane emitted by livestock and nitrous oxides released from crop fertilizers. Animal manures are also an important source of ammonia, a key acidifying gas.

3.3 Acidification

The past and present

The acidification of the environment has been a prominent factor in North America and Europe for at least the last two decades (see also Tolba *et al.*, 1992). The problem of acidification arises when two key conditions occur.

First, a region has a high level of economic activity with extensive use of fossil fuels, leading to large atmospheric emissions of acidifying pollutants. These emissions must be plentiful enough to be transported through the atmosphere for long distances in significant quantities. A summary of current and assumed future sulphur emissions, estimated by various sources, is given in Table 3.1.

Table 3.1. *Recent and projected sulphur dioxide emissions estimated by various sources*

	1990	2000	2010	Source
	teragrams sulphur			
Europe	19	11	7	Foell *et al*., 1995b; ECE/EB.Air/40;
	25			IMAGE 2.1 Baseline-A.*
Asia	17	27	39	Foell *et al*., 1995b;
	18			Barrett, 1992;
	17			IMAGE 2.1 Baseline-A.*
USA	11	8	7	Foell *et al*., 1995b;
	11			IMAGE 2.1 Baseline-A*.
China	11	17	24	Foell *et al*., 1995b;
	10			Barrett, 1992;
	12			IMAGE 2.1 Baseline-A.*
India	2.3	3.3	5.5	Foell *et al*., 1995b;
	1.9			Barrett, 1992;
	2.0			IMAGE 2.1 Baseline-A.*
Other regions	3.8	6.2	9.6	Foell *et al*., 1995b.

* Including SO_2 protocol

The second condition is that soil, forest and aquatic ecosystems in a region must be sensitive to these acidifying pollutants. Up to now only the second condition has occurred in some developing countries or countries in economic transition. Rodhe *et al.* (1988) identified schematically areas in which acidification might represent a serious threat in future. This identification was done on the basis of expected future emissions, population density and soil sensitivity (also reprinted in Tolba *et al.*, 1992). Areas at potential risk of acidification are indicated in the northern and southwestern part of South America, in the southeastern part of Brazil and the La Plata region, and in the southern part of West Africa (Kuijlenstierna *et al.*, 1995). Recent assessments have identified northern and the central part of Europe (Hettelingh *et al*., 1995a), and the eastern part of China and southern parts of Asia (Hettelingh *et al.*, 1995b and 1995c) as regions at the greatest risk of damage as a result of acidification. Now, however, the first condition is also occurring in certain regions in Asia where there are rapidly expanding economies (e.g. Zhao and Seip, 1991; Khemani *et al*., 1989; Shindo *et al.*, 1994). At the moment, the tools for a full-scale assessment of acidification in all six regions are not available. Integrated assessment models have, however, been used for the areas most affected to date: Europe (Amann *et al.*, 1995) and Asia (Foell *et al.*, 1995a,b; Morita *et al.*, 1995). Some of the results of this work are incorporated in the results described below.

The future

The Conventional Development Scenario, assuming continued economic growth in developing regions, has been interpreted for the present analysis as involving increased use of fossil fuels (especially coal) and a sharp increase in emissions of acidifying pollutants.

Table 3.2 presents the projected emissions of one of the main acidifying pollutants, sulphur dioxide. This projection takes into account internationally agreed abatement plans of sulphur dioxide emissions in Europe, an interpretation of national plans in North America and Japan, and for other regions a linear reduction of emission factors in all sectors of 50% between the years

Table 3.2. *Emissions of sulphur compounds projected under Conventional Development*

		Partial controls assumed			Hypothetical benchmark: No controls assumed		
	1990	2010	2050	2100	2010	2050	2100
	Teragrams of sulphur						
North America	12	9	7	5	21	18	12
Europe and former USSR	25	19	15	12	35	41	34
Africa	2	4	8	21	4	17	41
West Asia	2	4	5	10	4	11	20
Latin America	4	5	7	7	5	14	14
Asia and Pacific	17	38	40	65	39	80	131
World	63	79	82	120	107	180	253

Source: Posch *et al*. (1996).

2000 and 2050. As theoretical benchmark, Table 3.2 presents the corresponding emissions assuming no controls after 1990 (emission factors constant in their 1990 values). the ‘no controls’ projections represent an extreme scenario because it is unlikely that industrialized countries will abandon their current laws for controlling emissions. It is also unlikely that local impacts of the extremely high sulphur dioxide emissions under the ‘no controls’ assumption would be tolerated in Asia without attempts to control these impacts (Posch *et al*., 1996).

The trend in sulphur dioxide under this scenario differs markedly between the regions. Emissions in Asia, notably China, increase rapidly, even with the controls assumed. At the same time, industrialized regions increasingly take emission-abating measures, and thus their emissions are decreasing, as indicated by the example of Europe in Figure 3.1.

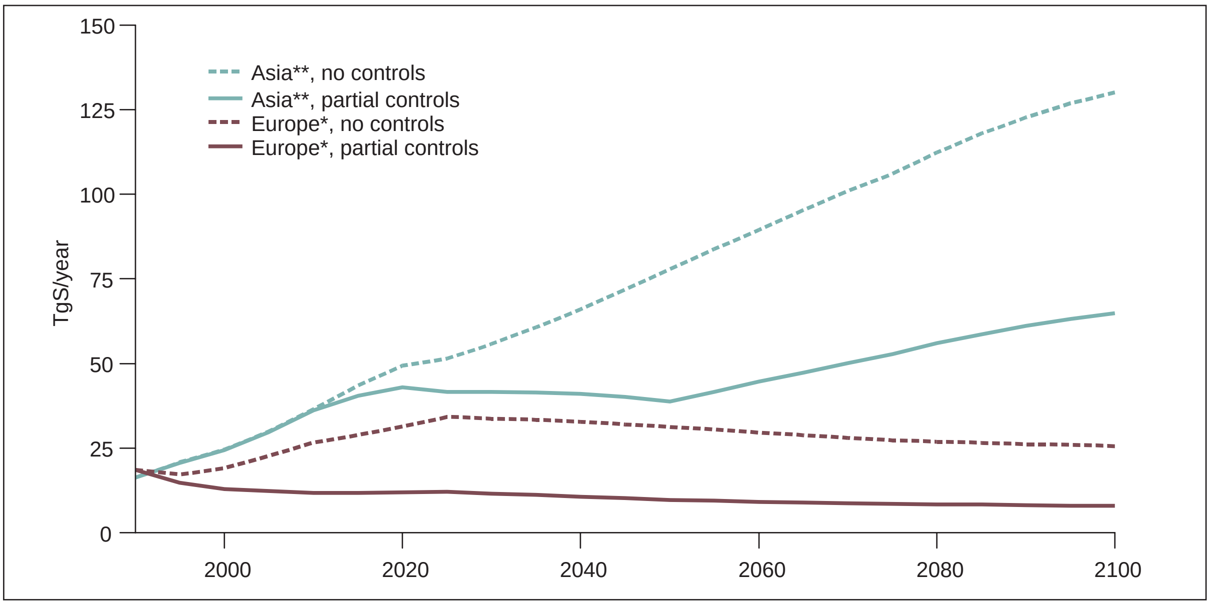

Figure 3.1. *Projected sulphur dioxide emissions for Europe and Asia*
Source: Alcamo *et al.* (1996) and Posch *et al.* (1996).
*   OECD Europe, Eastern Europe and the European part of the Commonwealth of Independent States
**   Not including Pacific

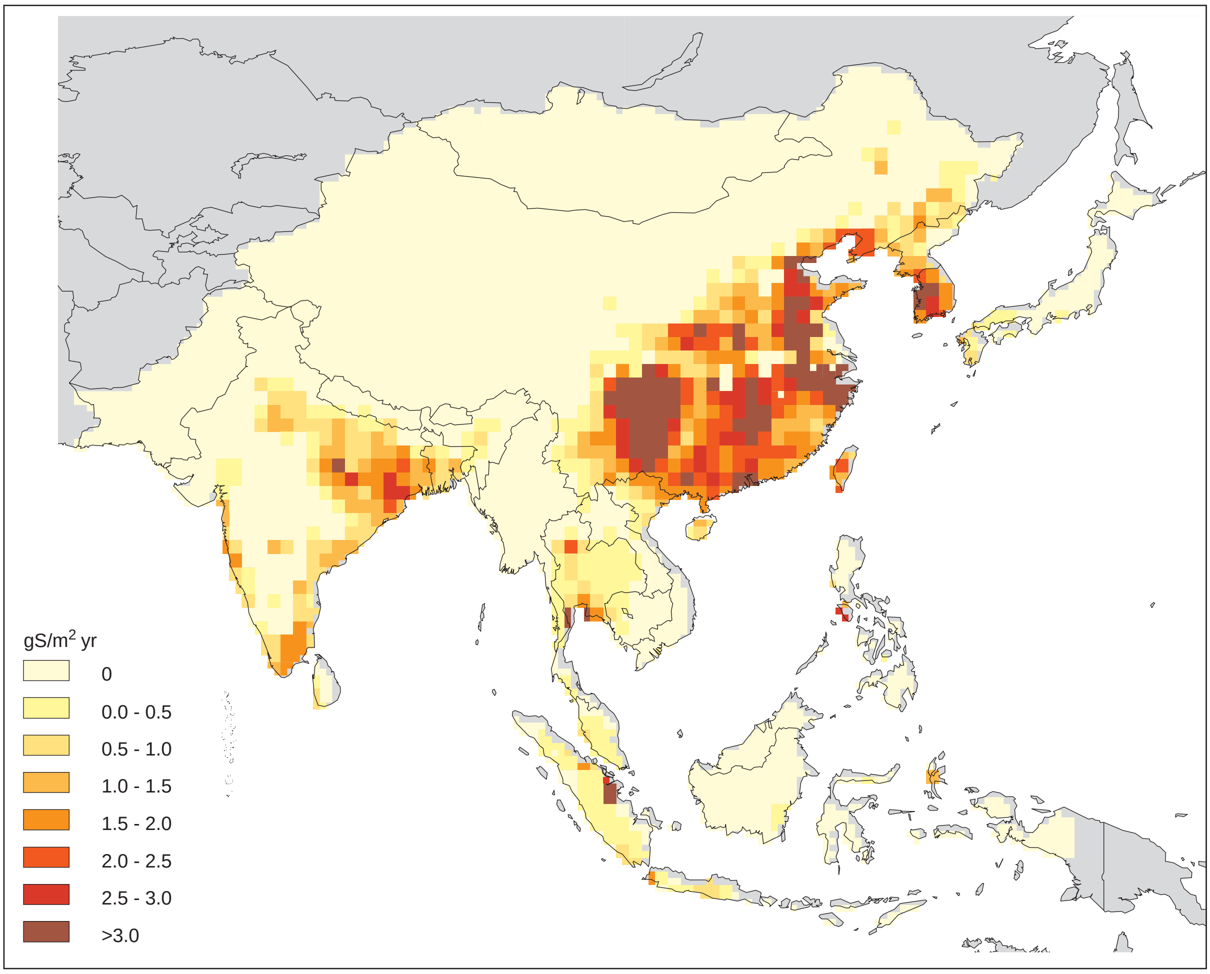

Figure 3.2. *Asian areas where critical loads of sulphur deposition are exceeded in 2050 assuming partial controls of sulphur dioxide emissions*

Source: Foell *et al*. (1995).

Note: Based on RAINS Asia simulation, Foell *et al.* (1995b) using IMAGE generated emissions and using the 5th percentile of critical loads in each grid cell of 0.5 x 0.5 degrees

An atmospheric transport model has been used to estimate how winds will transport and redistribute these acidifying pollutants throughout Asia (Arndt and Carmichael, 1995) and Europe (Barrett and Seland, 1995). This information has been combined with estimates of the sustainable acid deposition levels (critical loads) of local ecosystems (Hettelingh *et al*., 1995a,b; Hettelingh *et al.*, 1991; Downing *et al.*, 1993; Posch *et al.*, 1996). The result is a map depicting where important acid impacts may occur (Figure 3.2).

Comparison with other modelling studies, such as the Asian-Pacific Integrated Model (AIM) of Morita *et al.* (1995) seems to indicate comparable regional deposition patterns. Woodlands in some of these developing areas could deteriorate more rapidly, endangering supplies of fuelwood and other products. This deterioration would run counter to the goal of Agenda 21 of maintaining existing forests through conservation and management. In some of these areas acid deposition will lead to the release of toxic metals to groundwater and surface water, further contaminating drinking-water supplies, thus obstructing the Agenda 21 goal of minimizing environmental hazards to human health. Agricultural crops become increasingly subject to risk, not only because of the excess of critical loads (which may lead to long-term damage) but also because of high sulphur dioxide concentrations (exceeding critical levels), resulting in lower cereal yields.

3.4 Climate change

The past and present

The science of climate change is assessed periodically by the Intergovernmental Panel on Climate Change (IPCC). Since its establishment in 1988 by UNEP and WMO, IPCC has published a series of assessment reports, the first one (IPCC 1990) contributing to the establishment by the UN General Assembly of the International Negotiating Committee (INC) that prepared the Framework Convention on Climate Change (FCCC). In 1992, IPCC published an update (IPCC, 1992) that underpinned the negotiations on the Convention signed at the Conference on Environment and Development in Rio de Janeiro in 1992. A special report (Houghton *et al*., 1994) addressed specific questions raised by the Conference of Parties of the Convention on radiative forcing and emission scenarios. The second full assessment of IPCC was published early in 1996 (IPCC, 1996). This GEO contribution does not intend to add to these comprehensive assessments. Rather, it attempts to address some selected aspects of climate change from the perspective of integrated modelling.

According to the second assessment of the Intergovernmental Panel on Climate Change, 'the balance of evidence suggests a discernible human influence on global climate' (IPCC, 1996). The atmospheric concentrations of greenhouse gases have grown significantly and such a trend attributable largely to human activities (IPCC, 1996). Detection of impacts on ecosystems remains difficult. Recent results from computer models indicate that some degree of climate change may be virtually unavoidable in the coming decades. This is because current world economic growth and agricultural activity is leading to large increases in global emissions of carbon dioxide and methane and other greenhouse gases - a trend that will be very difficult to reverse in the short term. Moreover, even if emissions were immediately and sharply reduced, some climate change will occur because of the dynamics of the climate system. An inherent momentum makes the climate at present a product of accumulation of greenhouse gases of the past few decades. This underlines the importance of system inertia when evaluating impacts and response options.

The future

Up to now, most impact assessments of climate change have centred on industrialized countries at medium and high latitudes. This is partly because computer models predict that the largest temperature changes are likely to occur at these latitudes, but also since most research focuses on the regions where the most research funds are available. Nevertheless models also indicate that developing countries in low latitudes may experience important changes in climate, including crucial rainfall patterns (IPCC, 1990; 1996). Moreover, developing countries may be more vulnerable to climate impacts because their less developed economies and infrastructures impede adaptation. Indeed, results from studies completed recently indicate the special vulnerability of developing countries to impacts such as more frequent drought and coastal flooding (IPCC, 1996).

The consequence is that even under the most optimistic of conditions, global average temperature will still increase significantly (Figure 3.3), and important shifts could occur in global weather systems. These changes will affect both industrialized and developing nations, and could frustrate their ability to achieve the Agenda 21 goals of promoting sustainable agriculture, combating land degradation and desertification, managing fragile ecosystems and protecting freshwater resources. Based on computer model results, Figure 3.4 depicts an example of the possible impacts of climate change. It shows the area of tropical cereals with decreased yields caused by the changes in temperature and precipitation in the Conventional Development scenario (introduced in Chapter 2 of this report). This yield loss may be further exacerbated by excessive sulphur dioxide concentrations.

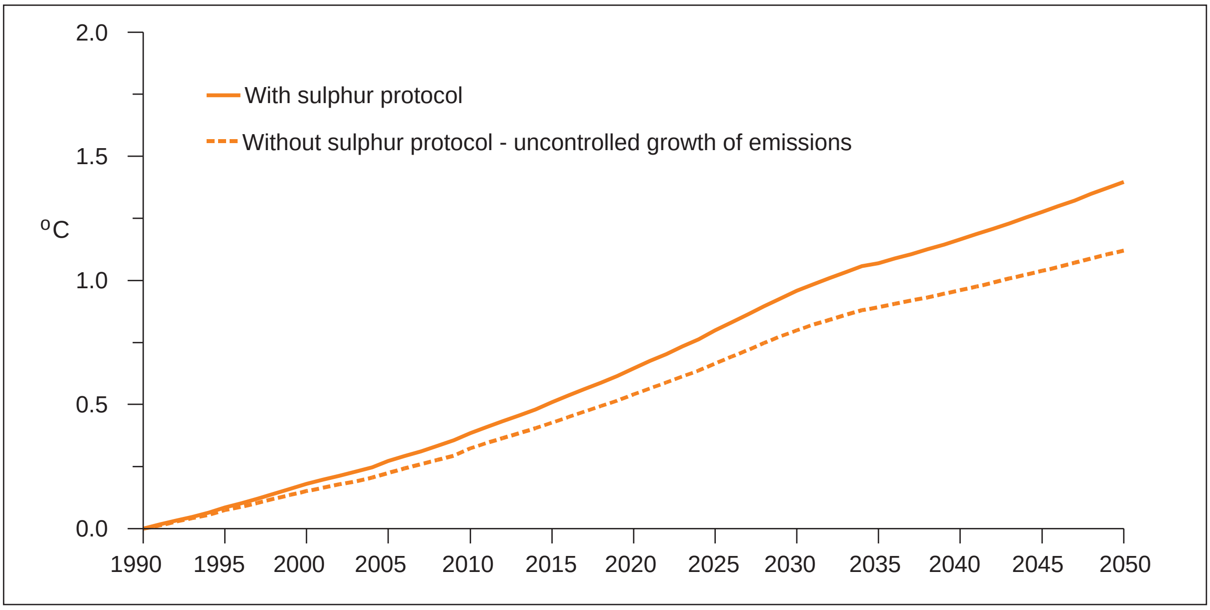

Figure 3.3. *Projected increase of global average surface temperatures*
Note: Based on the assumptions of the Conventional Development Scenario and two different atmospheric sulphate levels.
Source: Alcamo and Kreileman (1996).

Similar impacts can be expected in other regions. While, according to IPCC (1996), overall global food production may not be affected negatively by the projected climatic changes, there will be large regional differences. In some regions production may even be influenced positively, while in other vulnerable areas important negative impacts may occur. This is particularly important for developing countries in semi-arid zones, where the ability to adapt is lower than in the industrialized countries. Thus agricultural impacts such as these could worsen the economic conditions of these countries and run counter to the Agenda 21 goals of combating poverty, and promoting sustainable agriculture. On the other hand, increased imports of food from other regions could help developing countries to adapt to these impacts. These analyses underline the fact that it is not useful to focus on globally averaged climatic changes, but that regional 'redistribution' of climate (with the associated changes in agricultural productivity and trade patterns) is the important issue. Chapter 4 returns to the matter of landuse changes and food production, while Chapter 5 addresses the potential impacts of climate change on the quality of ecosystems. Although not dealt with explicitly in this chapter, it should be noted that the changing conditions for mosquitoes under different climatic conditions may increase the risk of vector-borne diseases like malaria and dengue and thus impact on human health.

3.5 Linkage of acidification and climate change

The past, present and future

Acidification and climate change are recognized as current or potential problems in both industrialized and developing countries. Recently, a better understanding as to how these two problems interact with each other has arisen (e.g. Houghton *et al.*, 1994).

First, increased combustion of fossil fuels simultaneously increases the emissions of many acidifying pollutants and greenhouse gases. Second, changes in weather patterns stimulated by climate change will also change the intensity and distribution of acid deposition. Third, the

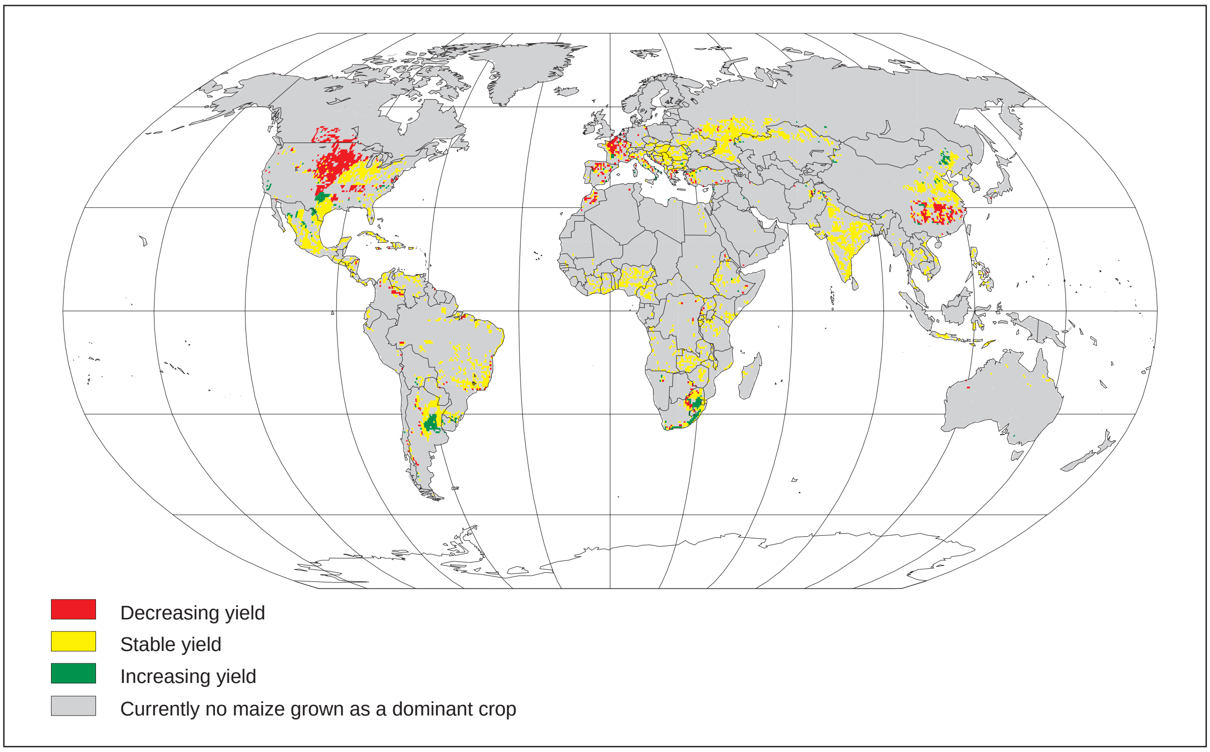

Figure 3.4. *Areas where yields of maize are projected to significantly decrease or increase because of climate change between 1990 and 2050*

Note: Calculations are derived from the IMAGE 2 model (Alcamo, 1994) for the Conventional Development scenario.

Source: Alcamo (1994).

emissions of acidifying pollutants, especially sulphur dioxide, lead to the accumulation of particles in the upper atmosphere which partly mask the global warming caused by greenhouse gases. This last effect has been simulated by a computer model for two variations of the Conventional Development scenario adopted in this report (Figure 3.3). If the level of particles in the atmosphere is assumed to remain constant at their 1990 value, then the growth in greenhouse gases would increase the global average surface temperature by about 1.5 ^{0}C from 1990 to 2050 (Figure 3.3, upper line). If, however, global emissions of sulphur dioxide increase parallel to the use of fossil fuels in developing countries, the mass of particles in the atmosphere will also increase and moderate this warming trend (Figure 3.3, lower line). The consequence of this is that if the emissions of acidifying gases were reduced while those of greenhouse gases were not, decreasing aerosol concentrations would 'unmask' the warming caused by the greenhouse gases. Finally, a fourth important way in which these problems will be connected is by virtue of their impacts literally overlapping in some areas. As an example, Figure 3.5 shows model calculations (linking the RAINS Asia and IMAGE models) of land areas that could be affected by both acid deposition and climate change. In the year 2050 about 12.5% of Europe and 7.3% of Asia (Alcamo *et al*., 1995; Posch *et al.*, 1996) are liable to be affected by both problems. In fact, after a first 'wave' of ecosystem degradation caused by acidification and the direct impact of sulphur dioxide, linked climate-acidification model simulations for Europe suggest a second 'wave' due to climate change some decades later.

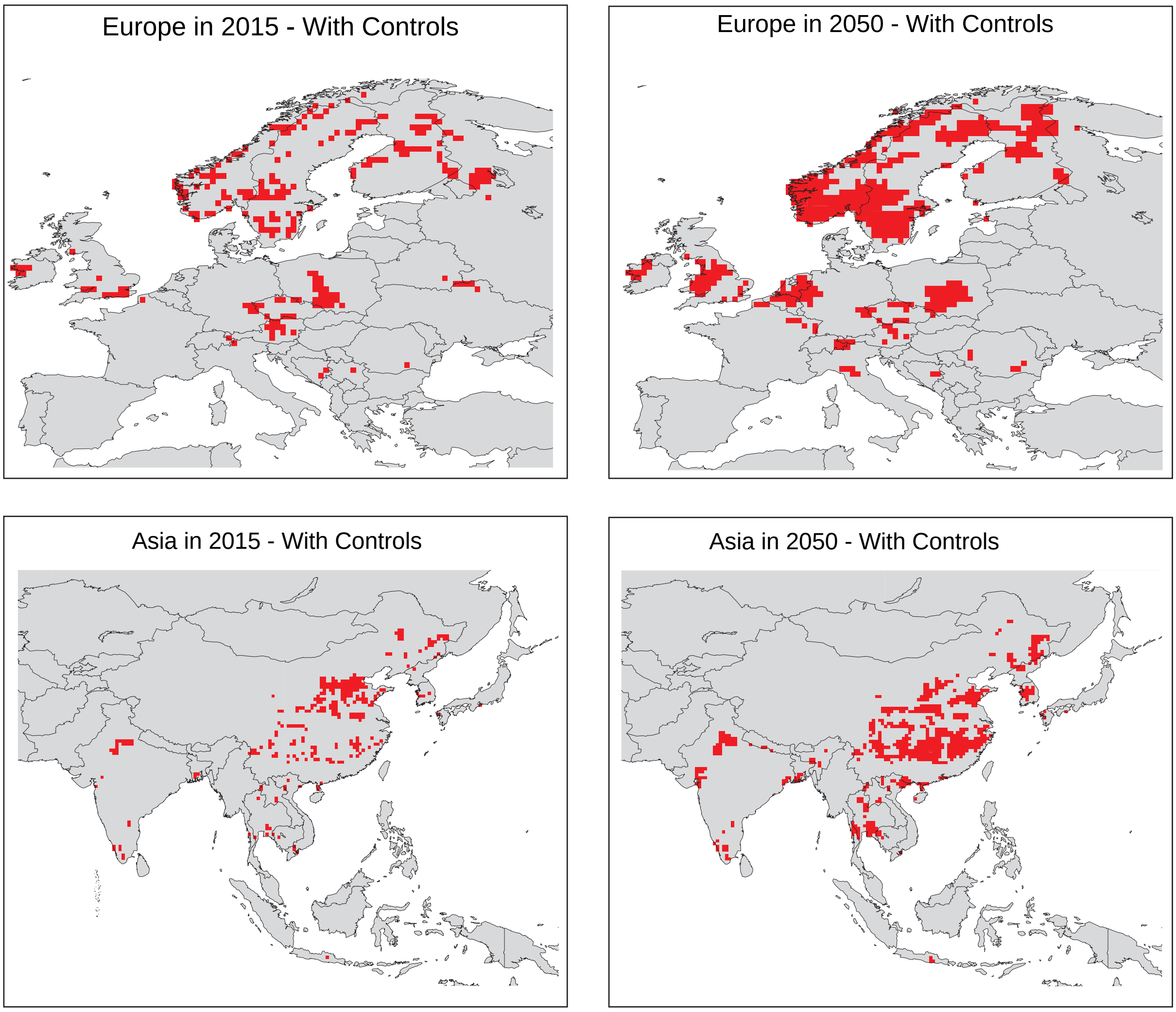

Figure 3.5. *Areas in Europe and Asia affected by both acidification and climate change*
Source: Posch *et al.* (1996).

3.6 The goals

A series of international conventions have stipulated targets for controlling acidification and climate change. The most important convention for the international control of acidification is the Convention on Long-range Transboundary Air Pollution of the United Nations Economic Commission for Europe and its protocols. This convention limits the emissions of sulphur dioxide and nitrogen oxides in North America and Europe. A protocol for the further reduction of sulphur emissions was signed recently. Unlike previous protocols, in which the agreed emission reductions were only addressed from the point of view of economic cost and available technology, this protocol also explicitly addresses the question as to whether the resulting acid deposition exceeds critical loads in Europe. So far there is no such framework enabling consensus-based multi-lateral negotiations on pollution prevention, supported by a multinational scientific network, for regions other than North America and Europe.

In terms of climate change, international action has been brought under the umbrella of the Framework Convention on Climate Change (FCCC), which stipulates the goal of stabilizing atmospheric levels of greenhouse gases so as to avoid ‘dangerous anthropogenic interference with the climate system’. Currently, as a first step towards achieving this goal, the industrialized (the so-called 'Annex I') countries have to roll back their greenhouse gas emissions to their 1990 levels by the year 2000. At the Berlin Climate Summit in 1995, the Parties to the Convention decided that these emission goals were inadequate for protecting the global climate. Hence they are now committed to adopting a protocol by 1997 which calls for stronger action to control the growth of greenhouse gas emissions. The current challenge to the Parties is to adopt a protocol that is not only politically and economically realistic, but also a clear step in the right direction to mitigating climate change. It is universally accepted that the industrialized countries must take the lead in controlling their emissions and transfer appropriate technology to developing countries.

In addition to these specific goals, which aim to reduce emissions and thus protect the atmosphere, Agenda 21 lists a number of activities, such as promoting sustainable agriculture, managing fragile ecosystems, protecting freshwater resources and combating desertification. These may be subject to the impacts of the changes discussed in this chapter. No political goals have as yet been formulated, for the wider set of issues related to the protection of the global geobiochemical cycles.

3.7 Are the goals considered potentially achievable?

Goals for mitigating acidification

The Convention on Long-range Transboundary Air Pollution provides an effective international framework for dealing with the transboundary aspects of, for example, acidification precursors in North America and Europe. International action to combat acidification in these regions has been codified in the form of protocols to the Convention. The First Sulphur Protocol, signed in 1985, called for a 30% flat-rate reduction in sulphur emissions in all signatory states (relative to 1980 levels). The Second Sulphur Protocol signed in 1994 will lead to further substantial reductions of emissions in Europe between 1990 and 2010 (see Table 3.1). Another important protocol, signed in 1988, freezes the emissions of nitrogen oxides in signatory states at their 1980/1985 level until 1995. The second nitrogen protocol is intended to include critical thresholds (i.e. critical loads for acidification and eutrophication, critical levels for nitrogen oxides and tropospheric ozone, and health guidelines for these pollutants). Taking these efforts and future trends in energy and the economy into account, it has been estimated that the ecosystem area affected by sulphur-based acid deposition may decrease from 19% to 10% in Europe (Hettelingh *et al.*, 1995a) in 1990 and 2010, respectively. Please note that unlike climate change, reductions in the emissions of acidifying gases result relatively quickly in decreasing deposition levels, followed by some delay from rehabilitation of the ecosystems affected. Typically this would take between 1 and 5 decades, provided that biogeochemical balances have not been distorted too much during the period in which the depositions took place.

There are no such political frameworks for tackling acidification in the developing world and hence there is no consensus-based mechanism for setting regional goals for anticipating and preventing acidification. However, as international technical frameworks emerge in the field of monitoring and modelling, the possibility of consensus-based approaches being followed in the future cannot be excluded. An example is the Acid Precipitation Monitoring Network in Asia which is currently convened by the Environmental Agency of Japan in collaboration with many other Asian countries.

Goals for mitigating climate change

Many industrialized countries are finding it difficult to comply with even the limited objectives of rolling back their emissions to 1990 levels by the year 2000. The long-term stabilization of atmospheric concentrations requires a reduction in global emissions. If emissions are allowed to increase in the developing countries, industrialized countries will need to reduce their emissions substantially below 1990 levels. Since total emissions must eventually be reduced, developing countries will, in the course of the next century, also need to reduce their emissions. Developing ways of distributing current and future responsibilities over Annex I (industrialized) countries and non-Annex I (developing) countries, as well as within these groups, remains a major challenge. In general, responses would be more efficient if countries could meet their commitments jointly. There are, however, some important non-economic caveats, such as the difficulties of organizing such a system internationally and the key ethical aspect as to whether rich countries should be able to 'buy' the cheapest options in poor countries.

In addition to the question of 'sharing the burden', the timing of measures is particularly important. There is currently a fierce debate between proponents of 'delayed response' and those of 'early action'. The advantages of delaying further emission reductions, as derived from economic analysis, are that autonomous technological development and discounting response measures makes future measures cheaper, while early commitment of capital is not needed (e.g. Wigley *et al*., 1996). Counter-arguments include the contention that early low-cost action will stimulate technological development and that the natural turnover of capital stock should be exploited (e.g. Grubb, 1996). Model experiments with the IMAGE model illustrate that the longer responses are delayed, the more drastic emission reductions will need to be, compared to early action, to reach the same end results in terms of climate change and the stabilization of emission levels (Alcamo and Kreileman, 1996). There are also significant 'interim' impacts caused by emissions in a period of delay until such time as convergence to the same level of impacts is achieved. This implies the additional advantage of early action to keeping options open (also for developing countries), thus increasing flexibility and avoiding 'interim' impacts. Another argument in favour of early action is that delayed response may make the costs of reclaiming lost resources, including agricultural areas, prohibitive for future generations.

With respect to the future of the world's energy system, an IIASA/World Energy Council study indicates that 'the single most important conclusion is that given the expected divergence of development paths after 2020 and the foreclosure of potentially desirable options if relevant policies are not initiated and decisions not taken long before 2020, action need will need to start now' (Nakicenovic and Jefferson, 1995).

3.8 Response options

There are a number of response options. For alleviating acidification, measures can range from 'end-of-pipe' techniques to structural changes in economic and energy systems. The second sulphur protocol, signed by a number of European parties to the Convention, is predominantly based on add-on technology of which the total annual cost for Europe in 2010 is estimated to be in the range of US$10 to 15 billion (1990 prices). The annual cost would have been considerably higher if an acceptable deposition limit (critical load) had not been established as an additional guideline for the optimal distribution of emission reductions over Europe. However, the inclusion of structural changes could have resulted in considerably lower abatement costs than those currently estimated, and the comparison between the cost of applying add-on technology and the cost of structural changes is complex. The cost calculation of add-on techniques has been adequately assessed at the micro-economic level, whereas the cost (and benefit) calculation of structural changes have yet to be elevated to a macro-economic level. When assessing the cost of structural changes in Asia, the cost of reducing sulphur dioxide emissions is estimated to be US$40 billion per year in China, India and Pakistan using domestic technologies and low sulphur fuels, and the same elsewhere using and improved technologies. This would lead to a reduction in emissions in 2020 of about 64% in comparison to 1990. If, however, best available technologies are applied, a cost of US$90 billion per year would be required to obtain a reduction in 85% of Asian sulphur dioxide emissions (Amann and Cofala, 1995).

The options for climate change have been presented comprehensively by IPCC (1990) and IPCC (1996). Here we will summarize a number of response options relating the impacts described in this chapter.

(i) Reducing fossil fuel use worldwide

Generally speaking, the issues discussed in this chapter all stem from a high level of economic activity that produces enormous emissions of polluting substances to the atmosphere. The most important source of these substances is the burning of fossil fuels. Hence, modifying the amount or type of fossil fuels burnt is an effective strategy for mitigating all of these problems at the same time. This could be considered as the next great transition in the world's energy system.

There are three general approaches to modifying fossil-fuel use:

- Low Carbon and Low Sulphur Fuels -- If economically feasible, switching to a fossil fuel with a higher heat content is an effective way to reduce emissions of acidifying and greenhouse gases.

- Renewable Energy -- Replacing fossil fuels with renewable sources of energy leads to drastic reductions in emissions per unit energy used.

- Energy Conservation/Efficiency Improvements -- Countless studies have identified the tremendous potential for reducing the amount of fuel needed to deliver a desired 'energy use' (i.e. a unit of residential heat or lighting) such as cogeneration and combined cycle systems.

The so-called LESS scenario (Low CO_2-Emitting Energy Supply System), developed by IPCC (1996), indicates that a global energy system with emissions of carbon dioxide below current levels by 2050 (compatible with stabilization of concentrations well below double the pre-industrial levels) is technologically feasible with current technology. Time will tell as to what extent such a scenario is also economically and politically feasible.

(ii) Reducing other global sources of acidifying and greenhouse gases

Industrial production and various forms of agricultural activity are further important sources of acidifying and greenhouse gases. There are many well-known 'technical fixes' for removing these gases from the industrial and agricultural waste streams of industry and agriculture. For example, desulphurization equipment can scrub a large fraction of sulphur dioxide from the stack gases of a manufacturing plant, while changes in feeding practices can reduce the amount of methane emitted by livestock. However, there is a limit to the volume of emissions that can be reduced at affordable cost by these and other technical fixes. An alternative long-term strategy is to replace the use of polluting products and processes by less-polluting products and processes. This is popularly known as 'Pollution Prevention'.

(iii) Planning to adapt to climate change

Even if the best efforts are made to reduce greenhouse gas emissions, some degree of climate change will inevitably occur. The time-frame required to adjust the climate system to changed emissions is decades to centuries, as compared to months for the deposition of acidifying substances. Hence, each national government should develop contingency plans for adapting to the impacts of climate change, such as coastal and river flooding, changes in water availability, changes in the occurrence of extreme meteorological events, shifts in natural vegetation zones, shifts in crop zones, and other changes that will have a major effect on the citizens and natural environment of a country. It is important to note (as IPCC did in 1996) that most of the adaptation options available in practice relate to the reducing the vulnerability of social, economic and environmental resources to climatic variables. Since climate is always variable, adaptation without long-term climatic changes is also useful. Important examples are the development of drought-resistant crop varieties, increasing the efficiency of water use, and avoiding the fragmentation of ecosystems.

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4 USE OF LAND AND WATER

4.1 The issue

Land and freshwater resources are at the core of the linkages between development and environment as they offer opportunities for settlement, food and wood production, and water supply, while representing the basic environment for most of the flora and fauna of this planet. Whereas in the previous chapter the disturbance of cycles was primarily determined by the demand for energy and raw materials, in this chapter the main cause of disturbance is the demand for food and water, as a result of population and economic growth. Research into the consequences of the driving forces in the Conventional Development scenario for global and regional land and water resources is reported. According to Cohen (1995) 'the human population now travels in a zone where a substantial fraction of scholars have estimated upper limits of human population size'. Consequently, the main questions are: to what extent can the increase in food and water demand be met and under what conditions, and how will the quality of land and water be affected? The calculations recorded in this chapter focus on the intensification and extension of agricultural land. The balance between self-sufficiency and imports, and the impact of the degradation of soil and water resources on the production of food and on the remaining natural land area are also discussed.

4.2 Food production and land use: past and present

Food production has not kept pace with population growth in most African and Latin American countries and in about half the Asian countries. In these countries the per capita food production was less at the end of the 1980s than at the beginning (IFPRI, 1995). In the last decade, the amount of grain per capita produced globally has fallen, and increases in rice and wheat yields are beginning to level off in some of the major producing regions. Increases in agricultural production have dropped from 3.0 per cent per annum in the 1960s and to 2.0 per cent per annum in the 1980s (Alexandratos, 1995).

Global food production can be increased either through *intensification* (raising the crop intensity by shortening the fallow period through the application of multi-cropping schemes and irrigation, or additional inputs to enhance crop yield) or by *land extensions* (cultivating additional land, primarily by converting forest or rangeland into farmland). The choice will be influenced by several factors, such as the availability of suitable land, its quality, the social and economic conditions and the availability of the necessary inputs. Regional food production can be supplemented by trade.

In the distant past, food production rose mainly because of a more intensive use of land and higher yields, but also because of expansion of agricultural land (Leach, 1995). In almost three decades (1960 - 1990) agricultural land area in the industrialized and developing world has increased by only 2.9 per cent and 15.4 per cent, respectively. However, these figures mask considerable regional variations (Africa 20 per cent; Latin America 27 per cent; Asia about 10 per cent) and do not include pasture land, the main contributor to the land extension in many regions (in Latin America, 5 to 6 times as much land is used for pasture as is arable). The mainstay of production increases in the past has been increased yields (through intensification), resulting from both application of new varieties and technologies derived from scientific discovery and improvements in agricultural management.

Currently about 4800 million ha of land is used for agriculture. This figure covers a range of diverse agricultural landuse types, ranging from very extensive to very intensive use. The 4800 million ha forms about -37 per cent of total global land area (FAO, 1995). Roughly one-third is arable land (1450 million ha, of which 10 per cent is irrigated) and two-thirds is permanent pastureland (3350 million ha). Figures on regional agricultural land use, compared with regional population figures, show large differences in the regional average ‘land per capita’ ratio. This ratio includes both arable and grazing land. The world lowest ratio values occur in Asia (about 0.4-0.5 ha per capita in 1990), the highest in Africa and Latin America (1.5-1.6 ha per capita) (Table 4.1). Two decades ago the ratio for Asia was around 0.5-0.6 ha per capita. In Africa and Latin America the ratio was 2.7 and 2.1 ha per capita, respectively. One reason for the low number in Asia is irrigation. Irrigation has provided opportunities for high cropping intensity and higher crop yields. In developed regions the land per capita values are almost three times those of Asia, but are low when compared to other developing regions (1.3 to 1.4 ha per capita).

4.3 Food consumption and production: the future

Food consumption

Global human food consumption figures show that while the world daily average per capita caloric intake of 2700 kcal is substantially above the critical level (1900 kcal per day per cap), there is a major difference in caloric intake between the developing (2470 kcal per day per cap) and the industrialized regions (3490 kcal per day per cap) (FAO, 1992). The Conventional Development scenario assumes that, taking the global average, nutrition will continue to improve. Figure 2.11 shows the projections of daily caloric intake for six regions in the world, indicating a convergence towards the current diets in Western industrialized countries. The global average intake is 2840 kcal per day per cap by 2015 and 3000 kcal per day per cap by 2050. Broken down, this would be 3490 kcal per day per cap in industrialized countries by 2015 and 2710 kcal per day per cap in developing ones, while the average intake is 3470 kcal per day per cap in industrialized countries in 2050 and 2930 kcal per day per cap in developing countries. Box 4.1 discusses the relationships between malnutrition, food security and food production.

Table 4.1. *Recent and projected agricultural area used per capita*

	1970	1990	2015	2050
	ha per capita			
Africa	2.7	1.6	1.2	0.9
North America	1.6	1.4	1.3	1.2
Latin America	2.1	1.5	1.2	1.0
Asia	0.5	0.4	0.4	0.3
Europe + former USSR	1.5	1.3	1.3	1.4
West Asia	2.0	1.2	0.9	0.6
World	1.1	0.8	0.7	0.6

Source: Based on IMAGE 2 calculations (Alcamo, 1994; Alcamo *et al*, 1996). Other sources used: FAO (1995) for historical data and Leach (1995) for scenario assumptions.

Box 4.1 *Food security, poverty and malnutrition*

The Conventional Development scenario projects a continuation of the increase in food intake, particularly in the developing regions. Notwithstanding its importance, this indicator does not address issues such as food security and nutrition. IFPRI (1995) reported that in 1990 about 800 million people were ‘food insecure’, i.e. lacking economic and physical access to the food required to lead healthy and productive lives, and around 185 million children under the age of six years were seriously underweight for their age. Food insecurity and child malnutrition is reported to be mainly concentrated in South Asia and is growing in Sub-Saharan Africa (Alexandratos, 1995; IFPRI, 1995).

At present - with the exception of civil war situations - malnutrition is not caused by a shortage of food, but by poverty: the lack of income to buy food or the lack of means (land, capital) to grow enough food. Over 1.1 billion people in the developing world live in absolute poverty, with incomes of only US$ 1 or less per person per day. The gap between rich and poor has become larger since 1960. Today 1.3 per cent of total global income is obtained by the poorest 20 per cent of the world population, while this was 2.5 per cent in 1960. About one million people lack access to health services and about 1.3 billion people, primarily in the rural areas of developing countries, drink unsafe water. (IFPRI, 1995)

Improving food security and nutritional status can be achieved through a set of concerted actions in which education, health care, safe water and sanitation, go hand in hand with improvements in the income levels and the empowerment of women. The purchasing power of the poor determines the extent to which food needs will be converted into effective market demand. If food scarcity is to be avoided, action is required to use the available land more efficiently and prevent land degradation, since the extension of cultivated area is not economically and environmentally a sound option in many regions.

What about the future? Notwithstanding the actions that are being taken to improve food security and nutrition, the FAO indicates in its 2010 report that the expectation that the world would now be on a firm path towards eliminating hunger and malnutrition has proved to be over-optimistic (Alexandratos, 1995). Studies by IFPRI for 2020 predict that the current uneven path in food security and nutrition is likely to continue (IFPRI, 1995). According to the FAO, the significant improvements in most of the developing regions are mainly due to increased domestic production and food imports. However, parts of South Asia, Latin America and the Caribbean are still in a difficult position and the prospects for much of Sub-Saharan Africa are bleak if the assumed improvements in agricultural productivity which are technically feasible and income levels are not achieved.

The Rome Declaration on World Food security (World Food Summit 1996) considers that it is intolerable and unacceptable that more than 800 million people do not have enough food to meet their basic nutritional needs. As response to this consideration the World Summit Plan of Action envisages an ongoing effort to eradicate hunger in all countries, with an immediate view to reducing the number of undernourished people to half their present level no later than 2015.

Supply and trade

In the Conventional Development scenario, global food supply will increase faster than the population. This is mainly because of the assumed shift in diets towards luxury food products, especially the consumption of animal products[1]. The Conventional Development scenario (Leach, 1995) assumes that in addition to increasing regional production, the regions Africa and West Asia will, in the major commodity sectors, import more and more agricultural products, while the more developed regions, in particular North America and Europe and the former USSR, are expected to produce more to counterbalance the mounting deficits. These findings are in line with the ‘FAO 2010’ study, which found that the already large present-day differences in self-sufficiency ratios between industrialized and developing regions will widen still further

[1] In the developing regions the intake fraction of animal products is assumed to rise by 30% to about 13 % of the total caloric intake by 2015 and 17% by 2050 scenario (Leach, 1995). In the industrialized regions it would remain stable at around 30% according to the scenario.

Table 4.2. *Projection of agricultural supply required*

	Cereals			Other crops			Animal products		
	1989	2025	2050	1989	2025	2050	1989	2025	2050
	million tons								
Developing	940	1882	2419	1870	3950	5502	307	903	1405
Developed	754	952	961	1110	1298	1262	565	666	660
World	1694	2834	3380	2980	5248	6764	872	1570	2065

Note: These values are based on the food intake data and assumptions as given in Raskin *et al.* (1996), which reports for 2025 instead of 2015. (See Appendix II.)
Source: Conventional Development scenario (Leach, 1995).

(Alexandratos, 1995). In Table 4.2 the total required agricultural commodity supply for 2025 and 2050 is given as assumed in the Conventional Development scenario.

Food production: Increases in food productivity
Various models have been developed for the projection and research of future developments in agricultural production (see Box 4.2). For this chapter the analyses are based on the IMAGE model (Alcamo, 1994; Alcamo and Kreileman, 1996) and an interpretation of the Conventional Development scenario. In the Conventional Development scenario (Leach, 1995) both cropping

Box 4.2 *Models and expert systems applied to longer term projections of agriculture and landuse related issues*

Global, regional and national landuse models, agriculture - economy models, and agricultural expert systems, support the scientific and policy communities with research information on state and longer term trends in food production and land use. These models and systems vary in concept, structure, level of integration and regional focus. The presently applied models or systems are continuously subject to improvement. What is common to models is their scenario-based simulation of developments in agriculture and land use. Expert systems, which are only partly based on models, such as FAO’s 2010 study (Alexandratos, 1995) attempt to sketch the ‘most likely’ development path for food and agriculture and not developments as desirable from a normative point of view (UNEP/RIVM/PE, 1996). Most of the models focus on 1 or 2 generations to come or on a specific point in time, whereas expert systems stop after 15-20 years.

The models mainly focus on production, trade, economics, and landuse - land-cover changes, taking into account major social and economic driving forces, agro-ecological conditions, suitability of land (climate, soil, water), landuse types, management level, and degradation of land, water and biotic resources. Policy relevance of these models and expert systems largely depends on the confidence in the ability of models and expert systems to provide adequate support in policy issues. Reliability and scientific soundness are therefore of utmost importance.

To request attention for natural resources degradation, UNEP has in 1996 convened a global food modelling workshop. The main goal of the workshop is to review performance and relevance of models for exploring future landuse changes at global and regional levels (UNEP/RIVM/PE, 1996). Especially of interest during the workshop was the impact of the degradation of land and water resources on food production and land use. In future GEO contributions more attention could be given to the available global and regional models and their performances, as well as to the role of environmental degradation on food production.

Some of the larger models and expert systems, frequently referred to and applied are the Land Use Change Project, Basic Linked System (IIASA), IMAGE model (RIVM), AIM model (JEA), IMPACT model (IFPRI), GCAM model (Pacific Northwest Lab.) and FAO’s expert systems (AT2010, Cappa). Note: this list is not complete.

intensity and yield improvements are addressed. In this chapter, these are taken as input assumptions for landuse calculations with the IMAGE model and discussed in the next subsection.

It is not likely that the cropping intensity in developed regions will change significantly, because of surplus production. In the developing regions cropping intensity figures are estimated to increase much more rapidly (a 15-20 per cent increase by 2050), both for irrigated and rain-fed agriculture.

Increases in yield are more important to raise productivity than increases in cropping intensity. The scenario assumes sustained increases in yield up to 2050. With the exception of China, the yields in the developing regions will not exceed those in the leading developed regions today. It is assumed that the generally poor yield performance in the past in Africa will be improved. The Conventional Development scenario assumes that agricultural production growth will fall to around 1.5 per cent per annum. The assumptions made in the Conventional Development scenario for the period up to 2010 are generally in line with those made by the FAO in its 2010 report (Alexandratos, 1995). According to FAO's report, intensification in land use will continue, especially in regions where land is scarce, such as South Asia, West Asia and North Africa. Table 4.3 shows the assumed crop yield for wheat and coarse grains.

The projected increases in yield are significantly higher for the developing regions than for developed regions. The highest increases in yield are assumed to take place in the first 35 years. Regional differences, not only in the rate of changes in production, but also in the absolute size, can be seen from Figure 4.1.

Discussion

The Conventional Development scenario assumes an agricultural transition to intensive land use. The projected transition in this scenario does not necessarily follow the concepts of sustainable land use. Intensification can only be achieved if social and economic conditions do not hinder the

Table 4.3. *Past and projected crop yields for wheat and coarse grains*

	1989	2025	2050	2050
	ton per ha			*index 1989 = 1*
Africa	1.17	2.18	2.70	*2.3*
Latin America	2.03	3.03	3.32	*1.6*
Middle East	1.18	2.53	2.95	*2.5*
China $^{+}$	3.19	5.13	5.67	*1.8*
S & SE Asia	1.50	2.83	3.24	*2.2*
North America	3.85	6.01	6.28	*1.6*
Western Europe	3.87	6.04	6.27	*1.6*
Eastern Europe	3.65	5.52	5.95	*1.6*
OECD Pacific	1.70	2.55	2.76	*1.6*
Former USSR	1.88	3.33	3.48	*1.9*

Notes: - Coarse grains are maize, rye, oats, barley, sorghum and millet.
- Values in Leach (1995) are reported for 2025 instead of 2015 (see Appendix II)
- Regions refer to the Conventional Development scenario regional breakdown, see Appendix II.

Source: FAO (1995) for historical data and Leach (1995) for Conventional Development scenario assumptions.

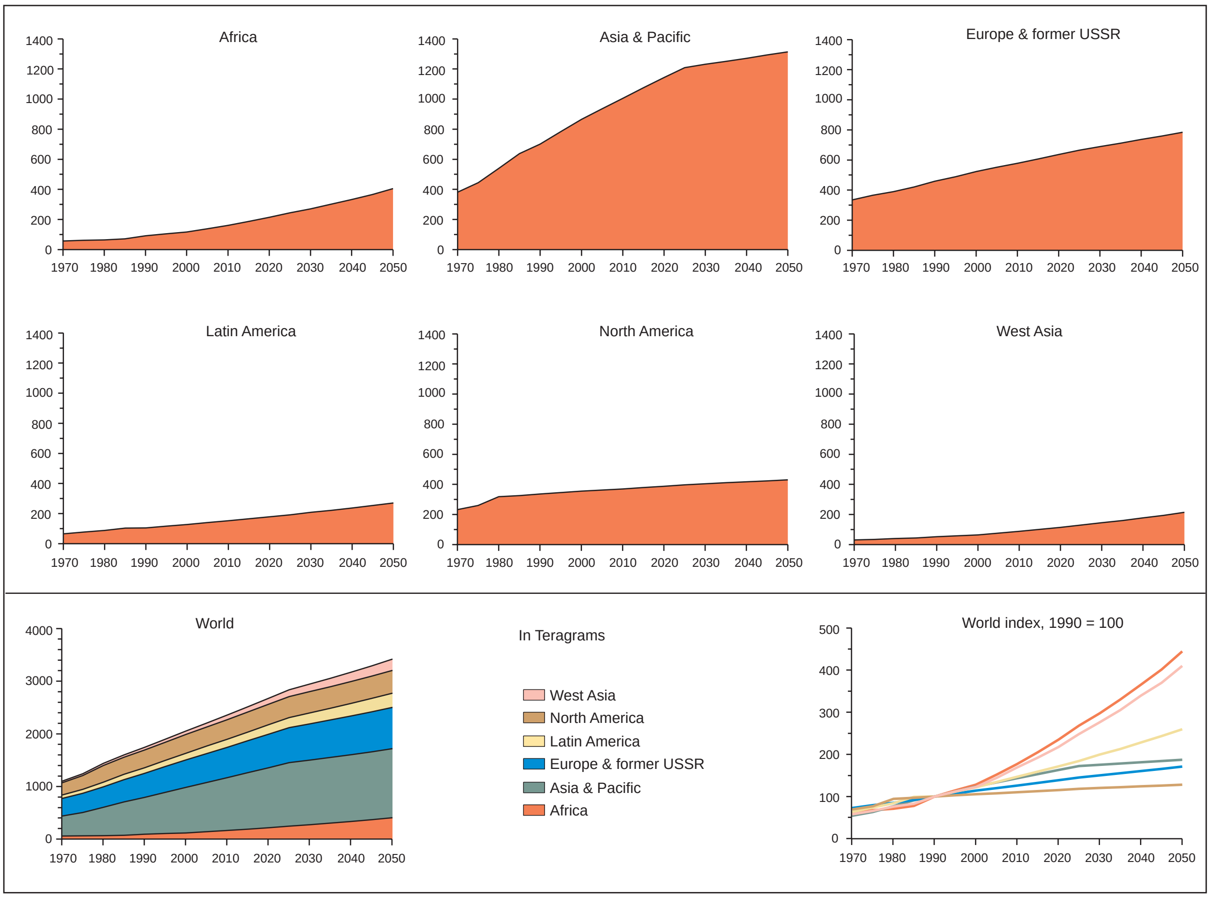

Figure 4.1. *Recent and projected production of cereals*
Source: FAO (1995) for historical data and Leach (1995) for Conventional Development scenario assumptions. Based on IMAGE 2 calculations (Alcamo, 1994; Alcamo *et al.* 1996) .

agricultural sector in its development. This can mean that access to markets is ensured and that farmers are supported by governments and extension services to produce more, while using the available natural resources in a sustainable manner. Factors that might limit production capacity or lead to the degradation of resources are restrictions in farmers' access to technological inputs and good seed varieties, a lack of infrastructure, a lack of capital, social factors such as archaic patterns of land ownership, inadequate levels of education and institutional factors that limit the efficient functioning of markets.

A factor that is not very well understood but which does affect agricultural productivity is the degradation of available soil and water resources[2]. There are few estimations of ongoing degradation and those in existence are poorly documented. At present, soil degradation is estimated to affect some 1.2 billion ha of land world-wide (10 per cent of the current agricultural land area). Water and wind erosion accounts for just over 1 billion ha of the total area degraded (Alexandratos, 1995; UNEP/ISRIC, 1990). The main causes of degradation are deforestation, overgrazing and the mismanagement of arable land. Other factors affecting soil degradation are nutrient depletion (Smaling, 1993), salinization and desertification (UNEP, 1991). Estimates

2 Global agricultural production models do not sufficiently take account of the adverse effects of soil degradation, possible shortages of irrigation water and salinisation of irrigated land. Also, the model used for this study does not yet consider soil degradation and water resources for irrigation. These issues require adequate model incorporation, yet in future reality their local impact on production (and production potential) can be dramatic.

indicate that each year 5-6 million ha are lost due to severe soil degradation. If this trend continues, several million hectares of additional land would be needed every year to offset the resulting loss of land. What is more, the additional land would in many cases be of lower quality and even more vulnerable to degradation. Another factor that affects agricultural production is urbanization. Often land areas suitable for agriculture are converted to urban land. This requires additional land and puts pressure on non-domesticated areas.

If it is not managed properly, intensification, the main driving force behind increases in productivity, will have negative consequences for environmental quality. These consequences may include increased scarcity of freshwater (because of irrigation), pollution of groundwater (with nutrients and/or pesticides), and increased demand for fossil energy (for making fertilizers and energy for mechanic traction). As well as contributing to pollution, food production is itself under stress of the air, soil and water pollution. Climate change may become a factor that has both negative and positive impacts on food production, which will differ per region. This has been taken into account in the calculations (see also Chapter 3).

4.4 Implications for land use

The assumptions of the Conventional Development scenario (Leach, 1995) have been analyzed using the IMAGE model (Alcamo, 1994; Zuidema *et al.*, 1994). This resulted in projections of the agricultural land area for 2015 and 2050. For a description of the IMAGE model and for a short description of the necessary adaptations to the scenario see Appendix III and II, respectively. The scenario trends with respect to population, economic growth, food demand, agricultural intensification and trade from Leach (1995) determine the way in which production increases can be achieved for the main agricultural crops and livestock management. It is assumed that additional land will not be cultivated as long as demand can be satisfied within the existing area. In Figure 4.2 the projected developments in the use of agricultural land (arable, pasture and marginal land) are given for the six regions.

Of the global land area, agricultural land currently comprises approximately 37 per cent. This percentage will have increased to 46 per cent by 2015 and to around 50 per cent by 2050. The ratio of pasture to arable lands remains relatively stable over time; the global average ratio is about two to one. As Figure 4.2 shows, there are very distinct regional differences in landuse changes. In the industrialized regions the total area of agricultural land increases by about 3 per cent by 2015 and 10 per cent by 2050, compared to 1990. (In North America this is 4 per cent by 2015 and 2 per cent by 2050. In Europe and the former USSR it is 2 per cent by 2015 and 15 per cent by 2050).

In contrast, in the developing regions agricultural land area increases by an average 33 per cent by 2015 and 45 per cent by 2050. The lowest increases are expected in Latin America, about 9 per cent by 2015 and 20 per cent by 2050 and in Asia, about 28 per cent by 2015 and 20 per cent by 2050. In the latter case, this is related to the limited possibilities for further expansion of agricultural land. But in West Asia and Africa, increases in agricultural area are much higher. In West Asia and in Africa the increases amount to about 50 per cent by 2015 and almost a doubling by 2050.

This increase in the area of cultivated land in Africa and West Asia results from a very sharp rise in demand and only moderate developments in agricultural management and technology, particularly the assumed continuation of traditional animal husbandry farming systems which require a lot of grazing land. If - in contrast to the assumptions - the increase in demand could be

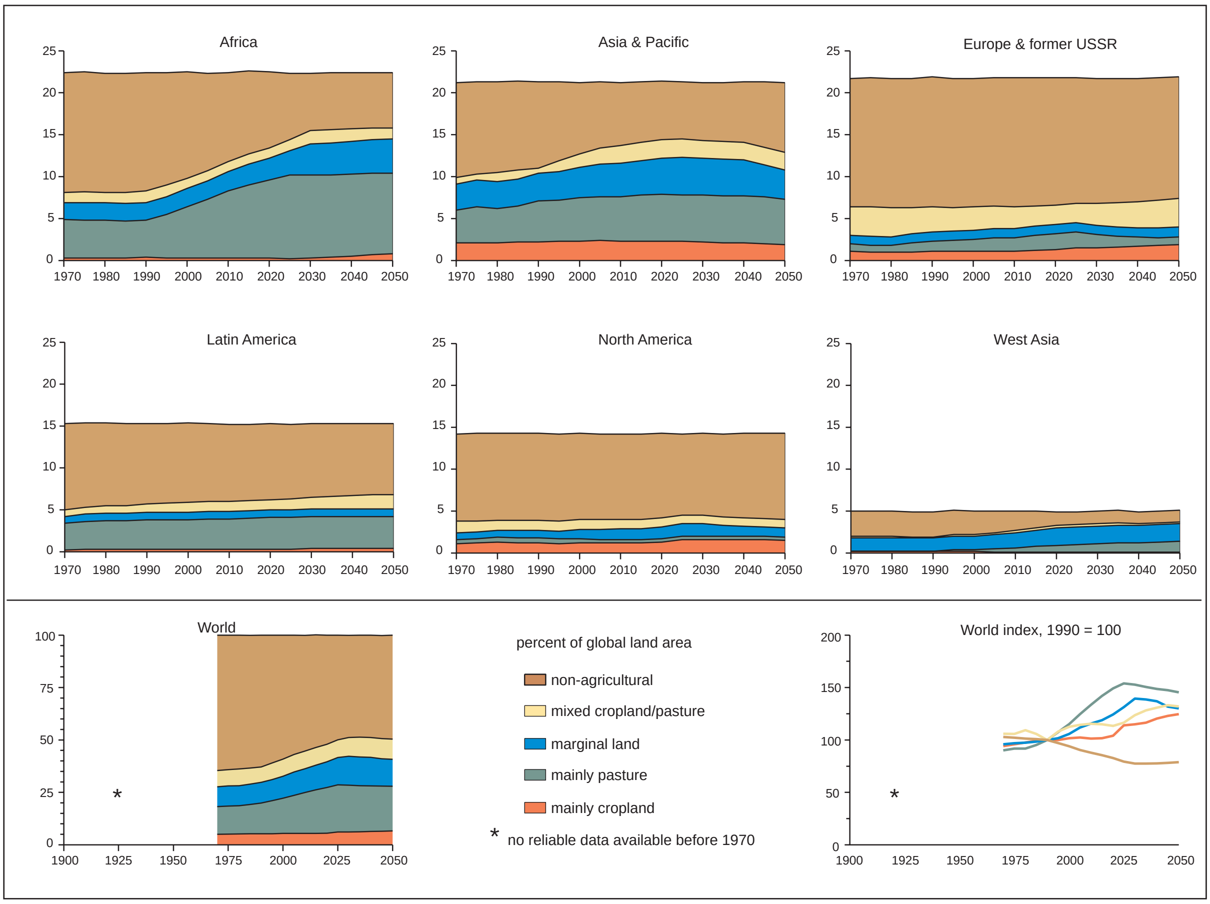

Figure 4.2. *Past and projected land use*
Source: FAO (1995) for historical data and Leach (1995) for Conventional Development scenario assumptions. Based on IMAGE 2 calculations (Alcamo, 1994; Alcamo *et al*. 1996) .

met with more elaborate traditional farming systems, the increases in agricultural land area would probably be less dramatic. Such systems require more input and better management but give more output per unit area of land. Sensitivity analysis for a series of farming systems would have been needed for a better understanding of the future land demand but this was outside the scope of the present scenario and analysis.

Notwithstanding the assumed increases in productivity and in the total area of agricultural land, increasing imports of food to the South from the Northern hemisphere are necessary to meet the projected rapidly growing demand in the South. The increasing necessity to import food products had already been indicated during the compilation of the Conventional Development scenario with Polestar and was confirmed by the detailed environmental analysis with the IMAGE model. The continuing degradation of soils and the possibly insufficient access of farmers to technology may even increase the rate of land conversions and dependence on food imports in developing regions. Conversely, additional increases in productivity, notably in livestock management and production on marginal lands, may limit the conversion of natural lands.

Summing up, to meet the demand specified in the Conventional Development scenario, a considerable extension of the area currently used for agriculture is needed in addition to improvements in yields. The extension will go at the expense of remaining natural areas, notably in the developing regions, and in parts of Europe and the former USSR and North America. This is elaborated in Chapter 5.

Regional summary

Africa
Due to the projected increases in population and per capita food intake, total food demand in Africa is expected to grow 120 per cent by 2015 and more than 300 per cent by 2050. The combination of this high increase in agricultural demands, an assumed additional supply from food imports, and a moderate development in agricultural technology, translates food intake into an increase of 55 per cent in the total agricultural area by 2015 and an approximate doubling by 2050. The modelling results, following the assumptions of the Conventional Development scenario show that from 2020 onwards suitable land becomes scarce and the food supply comes under more and more pressure, mainly because of the expected low average yields. To overcome these threats, a strong agricultural development is needed in Africa that would lead to a faster increase in regional productivity and greater security regarding food supply.

North America
The projected low increase of the population of North America and the high but stable or even slightly decreasing average daily food intake means that only 15 per cent more food production is needed. The slight increase in agricultural production in North America is mainly caused by the projected export to developing regions. Because of the assumed continuity in technological development in agriculture, it is expected that this will take place on more or less the same total area of agricultural land. (However, the location where crops are grown by 2050 could be different because of climate change. See Chapter 3).

Latin America
With both population and per capita food intake in Latin America projected to increase, the total food demand will grow by 50 per cent by 2015 and will more than double by 2050. The combination of an increase in agricultural demands and a successful implementation of agricultural technology is expected to lead to a 10 per cent increase in the total agricultural area by 2015 and about a 20 per cent increase by 2050. This includes the land required to produce for export, especially maize, after 2030.

Asia and the Pacific
The same picture emerges for Asia and the Pacific as for Latin America: an expected increase in food demand of about 50 per cent by 2015 and about 100 per cent by 2050. Combined with an assumed additional supply from food/feed imports and the continuation in implementation of agricultural technology, total agricultural area is due to increase with almost 30 per cent by 2015, and then decrease somewhat, resulting in an overall 25 per cent increase between 1990 and 2050. Both China and India are projected to face problems in the expansion of agricultural land by the beginning of the next decade. To overcome the growing shortage in land area, likely solutions for Asia are further implementation and development of agricultural technologies, and an increase in imports.

Europe and the former USSR
Given the small projected increase in the population of Europe and the former USSR and an unchanged daily food intake per capita, only 13 per cent more food production is needed in this region. The projected increase in total production is caused mainly by demand for export to developing regions. Notwithstanding an assumed continuity in technological development in agriculture, it is expected that the increase in regional demand, including demand for exports, will lead to some extra demand for agricultural land; 4 per cent more by 2015 and about 18 per cent more in 2050.

West Asia

The large projected increase in the population of West Asia (including Turkey, Iran, and Afghanistan), even with a small increase in per capita food intake, cause the total food demand in the region to increase 110 per cent by 2015 and almost 300 per cent by 2050. Assumedly, this strong increase in demand, will be met by high additional supplies from imports and a moderately fast implementation of agricultural technology. On balance, these developments lead to a 55 per cent increase in the agricultural area by 2015 and an approximate doubling by 2050. The results show that from 2020 on, the area of available suitable land is completely used and the food supply comes under increasing pressure. This means that the projected further increase after 2020 would have to take place on lands that are in fact unsuitable and more vulnerable. It also indicates that the food supply comes under increasing pressure.

World summary

Total global food demand is projected to increase by 50 per cent by 2015 and by more than 110 per cent by 2050. The increase in agricultural demands and changes in patterns of consumption (less staple foods and more luxury products, which require more inputs) are partly met by and ongoing technological development in agriculture. On balance, these developments lead to a projected 27 per cent increase in the total agricultural area by 2015 and about 42 per cent increase by 2050. The regional results indicate that the large areas in Asia with a dense population will run out of available suitable land from 2000 onwards. They are likely to face growing pressures on the food supply unless the countries involved are able to improve their agriculture more than currently projected or to import food, mainly from industrial countries in temperate regions.

Discussion

Many reputable institutes and organizations have addressed such issues as future developments in the use of available land and water resources, land degradation, intensification versus land extension, and various aspects of self-sufficiency and international trade. Generally speaking, there are two kinds of perspectives: one optimistic and the other pessimistic. On the one hand there are the somewhat optimistic reports and publications. They assume that if technology and enhanced management are implemented successfully, demand can be met without reaching the biophysical limits of global food production (e.g. FAO, 1995; Alexandratos, 1995). On the other hand, more pessimistic voices are pointing out that: technological developments do not look so promising and will lead to non-sustainable agricultural practices; technologies are unevenly spread across the world; the developing regions in particular are depending increasingly on exports from the more developed regions, and in future a growing number of people will lack food security and be malnourished (e.g. Brown, 1996). This difference in perspective can be largely attributed to different estimates of the future availability of suitable soil and water resources; the way these resources will be used, or misused (sustainable versus non-sustainable use); the impact of environmental pollution on agriculture (due to climate change, acidification and water pollution) and agriculture’s contribution to the general pollution of water, air and soil.

The Conventional Development scenario is optimistic in that it assumes significantly higher productivity in agriculture, but pessimistic in terms of a reduction in self-sufficiency in some developing regions and the negative effects of necessary land extensions on biodiversity (see Chapter 5). The clear differences in vision between leading experts on achievable/attainable developments in agriculture have received surprisingly little attention thus far.

4.5 Fresh water

Introduction

The small number of freshwater resources that is technically and economically accessible to humans is unevenly distributed in space, time and type. This leads to a wide range of water-related problems, including interstate conflicts, competition in use and health problems (Gleick, 1996). In the next century, these water-related problems are expected to increase because of growing water demands caused by population growth, enlargement of irrigated area, and industrial activities, while in the meantime the supply remains about constant or might increase only slightly under climate change.

Freshwater demand

The Conventional Development scenario postulates a decrease in aggregate water intensity (water requirement per unit GDP) because of increasing water efficiency and gradual shifts to less water-intensive economic activities. Freshwater demands in the Conventional Development scenario have been projected for each region for domestic, industrial and agricultural use. Figure 2.12 (Chapter 2) shows regional and global developments in freshwater withdrawals according to this scenario. Global demand is projected to increase from 3000 km^3 in 1990 to about 3700 km^3 in 2015 and about 4300 km^3 in 2050 (Raskin *et al.*, 1995b). The historical growth in total withdrawals in the industrialized regions slows down considerably in the scenario and withdrawals in North America eventually decrease. Regionally, large increases in water demand are expected up to 2050 in Africa, Latin America, China and South and Southeast Asia. By 2050 the projected rate of increase in Asia is almost double that of total global withdrawals.

Presently, irrigation accounts for around 70 per cent of total water withdrawal, industrial use for about 22 per cent and domestic consumption for the rest. As far as future domestic, industrial and agricultural (irrigation) withdrawals are concerned, the first two categories show a slight increase in the industrialized regions and a marked increase (more than 3 to 5 times) in the developing regions. Agricultural withdrawals show a slower increase, with a global average of about 20 per cent by 2050 (with the fastest increase in the period up to 2025). The increase in the use of water for irrigation is due mainly to the assumed extension of the irrigated area. In fact global irrigated area increases about up to 35 per cent by 2050, while irrigation intensity (m^3 per ha) decreases only slightly.

The projected increase in global water demands (expressed as withdrawals, 2050 compared to 1990) is a factor 2.12 for domestic use; 2.37 for industrial use; and 1.06 for agricultural use. The projected values are the result of a combination of increasing pressures and improvements in efficiency (Chapter 2, Figure 2.12).

A second component is the demand for domestic water supply and sanitation facilities, that are adequate to health and well-being. At present nearly two billion people lack access to clean water and sanitation, and over a billion people throughout the world are not served by appropriate sewage treatment systems (Gleick, 1996). This is despite the ambitions of the International Water Supply and Sanitation Decade (1980-1990) to provide everybody with adequate water supply and sanitation facilities.

Domestic and industrial users compete more and more with agriculture for limited water resources; this may be particular significant in some of the sub-regions in Asia and Africa. According to FAO, the need for more production might be likely to accentuate pressures on the water resources more than on land resources (Alexandratos, 1995). FAO highlights the growth in dependency of food production from irrigation-based agriculture, the competition between agricultural demands and domestic and industrial demands (partly driven by price mechanisms) and the non-sustainable use of groundwater, which is leading to both quantity and quality problems.

Freshwater availability

Demand has to be met by either renewable water resources or by gradually depleting fossil groundwater. (Large scale desalinization is left aside here, because it is not a realistic option in most countries of the world). Renewable and available freshwater resources, either groundwater or surface water, are unequally distributed, with an abundance in Oceania and South America and shortages in West Asia and Sub-Saharan Africa. According to a water stress index in 1990 more than 30 countries were ‘water stressed’, including most of North, East and Southern Africa and West Asia. By 2025, 54 countries could face ‘water stress’, with about 23 facing absolute water scarcity (Engelman and LeRoy, 1993). While mankind uses only a small portion of the total global freshwater resources, water at the local and regional levels is becoming increasingly scarce in many areas. On a local scale serious problems can arise, which may have major implications for health and well-being of people, agricultural development and protection of ecosystems dependent on water resources.

Two other aspects need to be emphasized. First, the international aspect. Availability presents the most notable problem in areas of water scarcity where rivers and other water resources cross borders. This is best illustrated by the increasing number of conflicts over water, e.g. in West Asia, and in the Indogangean plain. Secondly, major cities, in particular the fast-growing megapoles in developing countries, require enormous efforts in water supply and sanitation and groundwater management. Also in areas outside cities, lack of adequate supply can be the cause of water problems even if there is enough water available to meet demands. The lower part of the Danube valley is a case in point. The situation is often aggravated by the low quality of the water resources. However, the following analysis does not consider water supply issues but focuses on the preceding issue of the ratio between demand and renewable resources.

For the Global Environment Outlook, a first global analysis has been made of the demand versus availability of water at the level of river catchments. This model based analysis is based on physical processes and local conditions following a geographical explicit approach according to Klepper *et al.* (1995). The model, which is still in a preliminary state, is briefly described in Appendix III. Flows of upstream sub-basins to downstream basins and the distribution of supply and demand within a sub-basin were taken into consideration. It has been used to estimate at a detailed level water availability and water demand, following the assumptions of the Conventional Development scenarios. The ratio between availability and demand is defined as ‘water demand satisfaction ratio’. The ratio was calculated for all 1165 river basins[3].

Projections for the years reported were based on monthly averages, with the calculations for 2015 and 2050 assuming a year with average climate characteristics. In Figure 4.3 the satisfaction ratios of water demand for 1990, 2015 and 2050 are visualized on a river catchment level.

The results in Table 4.4 show that by 1990 in about 12 *per cent of the total world’s area*, people have moderately severe to severe problems with the availability of sufficient freshwater. In about 18 per cent of the land area, people have few to moderate problems with the availability of sufficient fresh water. In about 22 per cent of the world’s land area, water availability seems to meet demand.

[3] However, those with low population densities were excluded from the results (Klepper *et al.*, 1995; Klepper *et al.*,1996). Thus, a water demand satisfaction ratio for 53 per cent of the global land area (where 95 per cent of the total population lives) is presented. The remaining 47 per cent tend to be either extremely dry, cold or have very high precipitation.

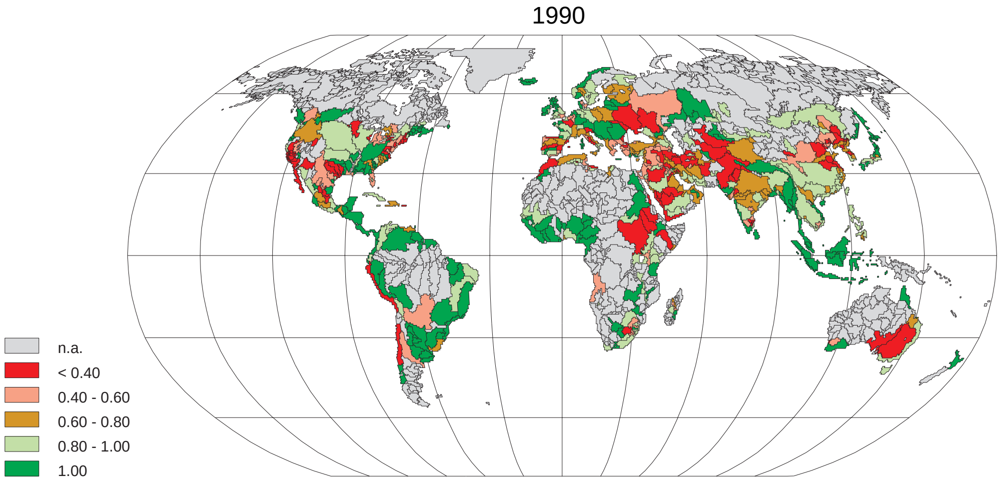

Figure 4.3a. *Water demand satisfaction ratio per catchment area in 1990*

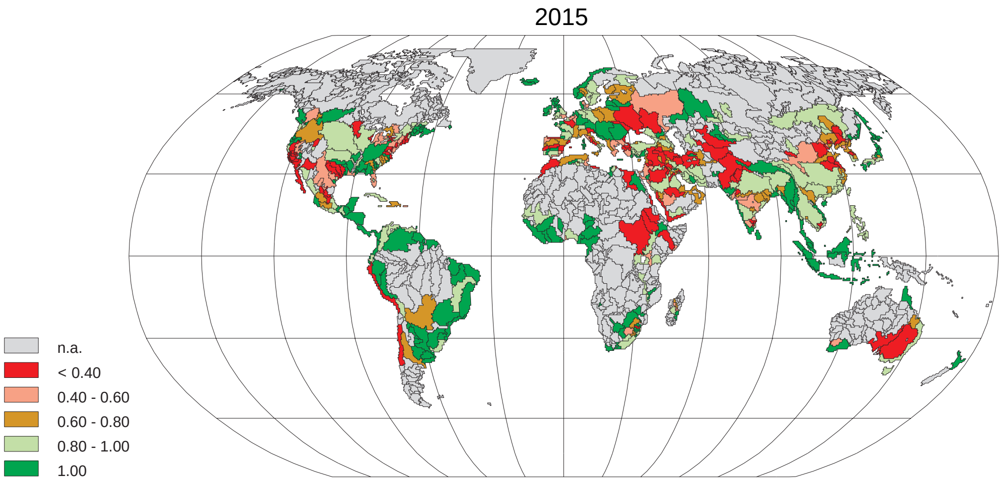

Figure 4.3b. *Projected water demand satisfaction ratio per catchment area in 2015*

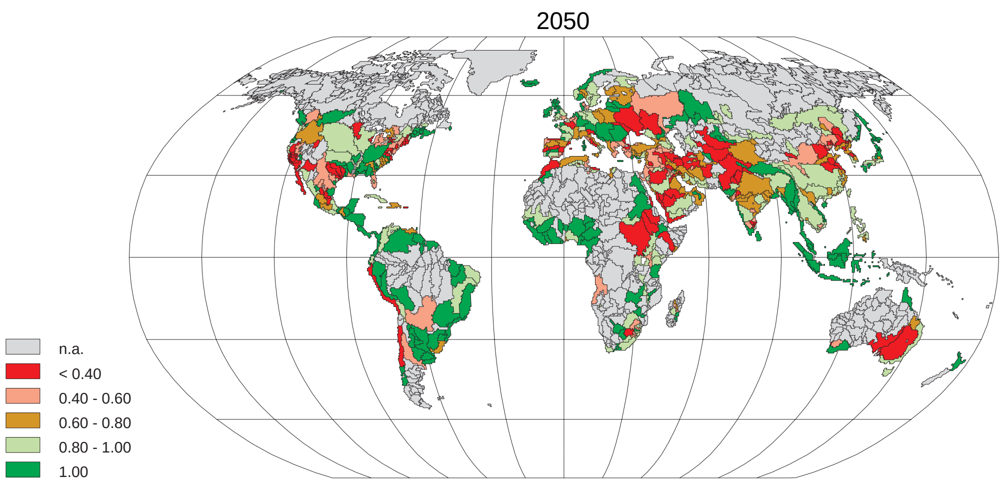

Figure 4.3c. *Projected water demand satisfaction ratio per catchment area in 2050*
Note: n.a. = not applicable, because of very low population density
Source: Klepper, *et al*. (1996, forthcoming).

Table 4.4a. *Distribution of catchment areas by satisfaction ratio of freshwater demand under the assumptions of Conventional Development*

	no problems	few to moderate problems	moderately severe to severe problems
	% of global land area		
1990	22	18	12
2015	18	21	14
2050	15	22	16

Note: The remaining 47% of the global land area concerns catchments areas with low population density (totalling 5% of the global population), where the analysis is not applicable.
Source: Klepper *et al*. (1996, forthcoming).

Table 4.4b. *Number of people by satisfaction ratio of freshwater demand under the assumptions of Conventional Development*

	no problems	few to moderate problems	moderately severe to severe	*analysis not applicable*
	million			
1990	1300	2400	1500	*300*
2015	1700	3400	2100	*500*
2050	2200	4700	2800	*700*

Source: Klepper *et al*. (1996, forthcoming).

This relates to 27 per cent, 44 per cent and 24 per cent of the global population, respectively. (The remaining 5 per cent of world population lives in 47 per cent of the area where this study is not applicable). The areas most affected were West Asia, and parts of India, Africa and the United States. Between 1990 and 2015, the area classified as 'no problem' is projected to decrease from 22 to 18 per cent. By 2050, the area classified as 'no problem' has decreased to 15 per cent.

The number of people that face 'moderately severe to severe' water quantity problems in 1990 is 1.5 billion; for 2015 this is 2.1 billion; and 2.8 billion for 2050 (Table 4.4b). The number of people that face 'few to moderate problems' in 1990 is 2.4 billion; for 2015 this is 3.4 billion; and 4.7 billion by 2050 . The number of people with 'no problems' in 1990 is 1.3 billion; for 2015 this is 1.7 billion, and for 2050, 2.2 billion.

Thus, the pattern emerging from the detailed analysis of this scenario is that availability of sufficient fresh water will remain a continuous topic of concern and shortage will affect a growing number of people. The improvements in efficiency that are assumed in the projected scenario do not diminish the overall pressures on freshwater resources.

Next to water demand, water availability is likely to change in the future. Global climate change probably will cause wider variability in precipitation, leading to variations in water availability (Darwin *et al.*, 1995; Morita *et al.*, 1995). According to projections with the Asian-Pacific AIM model (Morita *et al.*, 1995) the widely expected doubling of atmospheric carbon dioxide concentrations will cause half the world area to have higher water discharges, particularly in northern India, northern Russia, the northern part of North America. By contrast, reductions in

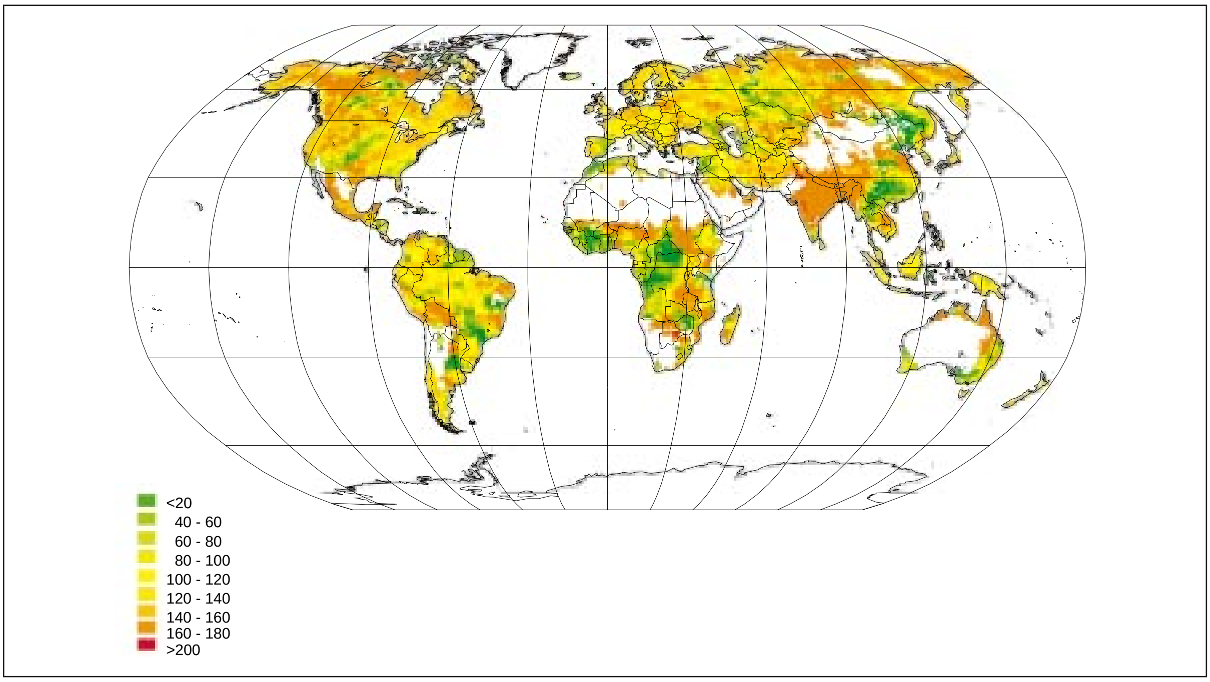

Figure 4.4. *Water discharge: projected changes caused by climate change*

Note: Per cent relative to current discharge. Projected for a doubling of atmospheric carbon dioxide relative to pre-industrial levels.

Source: Morita *et al.* (1995).

water discharge are most significant in developing regions (see Figure 4.4). From the above study it can be concluded that in the future, availability of freshwater, especially in parts of Africa, West Asia, Southern India and China, is likely to become more and more affected by social, economic and environmental processes. Using various climate (GCM) scenarios, the United States Department of Agriculture (Darwin *et al.*, 1995) calculated the impact of climate change on water availability and runoff assuming a doubling of atmospheric carbon dioxide concentrations. They reported that although world-wide water availability is likely to increase (6-12%) for the world as a whole under climate change, shortage could occur in some regions and might exacerbate problems with allocating water resources.

Water management

The growing demands for water will increase the risks of conflicts over use of scarce water within a country (competition between sectors) or between countries. It would seem that such conflicts can only be avoided when water distribution between users can be agreed upon. This then would require an integrated river basin approach, legal provisions, administrative rules and regulations, pricing mechanisms and control and monitoring. Therefore, the establishment of functional and effective river-basin boards for water management, and distribution in catchment areas, is one of the major challenges if sustainable development is to be achieved. In the past two years, a methodology for integrated river basin assessment to promote sustainable water use has been developed and pilot-tested in the Zambezi and Dongjiang catchment areas (Bannink, 1996; Heij and Bannink, 1996 ; Li Kai-Ming *et al.*, 1995).

Apart from the challenge to provide adequate water and sanitation services, water needs to be recycled after being used and discharged. To date, less than 4 per cent of wastewater streams is treated before discharging. This lack of treatment causes substantial water pollution problems. Water that is polluted or contaminated with pesticides or nutrients often affects health, ecosystems and the economy and is a limiting factor in irrigated agriculture. Rivers, lakes and groundwater aquifers are increasingly becoming contaminated by biological and chemical wastes, if a survey in Western and Eastern Europe is indicative for other regions as well (EEA, 1995). Moreover, it needs to be emphasized that the quality of domestic water is not only affected by the quality of its main source (lake, river or groundwater) but also by its handling during transport to the end-user. This often impacts directly on health (see Chapter 6).

4.6 Are the goals considered potentially achievable ?

The main challenge with respect to the use of land and water, according to Agenda 21, is to produce sufficient agricultural and forestry products to meet increasing human demands and to supply sufficient water for domestic, industrial and agricultural use, while at the same time safeguarding the environment and protecting fragile ecosystems. This can be achieved mainly by increasing production on land already in use and by avoiding further encroachment on land that is only marginally suitable for cultivation. The Desertification Convention calls for long-term integrated strategies that focus simultaneously on areas at risk, on improving agricultural productivity, and on the rehabilitation, conservation and sustainable management of all land and water resources.

In the Conventional Development scenario, the demand for food and water is assumed to be met at the global and regional levels, except for Africa and West Asia where it is assumed that food will be imported. However, much more detailed calculations with the IMAGE model, taking into account soil, climate and existing land use, show that the Conventional Development scenario[4] implies that the demand for food also cannot be met in China and India in the beginning of the next century. Therefore, to fully satisfy the regional demand as initially assumed in the Conventional Development scenario, more food imports will be needed, especially in China, India and Africa.

The developments required to correct this imbalance pose an ever increasing risk to land and freshwater resources affected by the negative side-effects of intensification and land extension in agriculture, particularly in the developing regions. The projected extension of agricultural land will bring food production into conflict with other land uses, especially with the remaining non-domesticated areas in parts of the developing regions. As will be elaborated in the next chapter, this will have major consequences for fragile ecosystems and the associated bio-diversity.

The efficient use of water in irrigation - increasingly in competition with household and industrial use - is a crucial factor in achieving the necessary yield improvements in developing regions. On the sub-regional or local scale serious water-resource constraints already exist. This not only affects agriculture, but also health.

In the analysis of the scenario it is concluded at the global and regional level (except for Africa, West Asia and Asia) that the land and water resources required for future food production would be available and agriculture is likely to produce sufficient food to support the demographic transition. However, this is probably by no means the case at the sub-regional scale, as witnessed by the many current natural disasters and by environmental degradation. Although advances are likely, there is no indication that future capabilities will be fundamentally different from the present. Besides, it is important to be aware that the findings in this chapter are already based on

[4] See Appendix II for details on the interpretation of the Conventional Development scenario.

scenario assumptions that intensification develops steadily and successfully, that trade continues (implying that importing countries can afford this) and that the resources prove to be sustainable. To achieve this in the foreseeable future is already an enormous challenge.

4.7 Response options

Assumedly, intensification of agriculture will continue to be the main means to keep food production apace with future demands. However, to achieve the goals set out in Agenda 21 it is important that agricultural productivity is increased in a sustainable way. This will require action in a number of fields, not only in agriculture, because a high level of intensification can conflict with sustainability.

However, even though intensification seems to be unavoidable, the area of agricultural land area will also need to expand in some regions. This extension is in the present scenario analysis projected mainly in Africa, West Asia and to lesser extent in parts of Asia and Latin America. It will put the remaining non-domesticated natural areas under further pressure. This pressure can be eased considerably by pushing ahead with improvements in the efficiency of both arable farming and animal husbandry in developing areas, both in the more suitable regions and more marginal areas. At the local and sub-regional level this requires an evaluation of the suitability and vulnerability of marginal land and sound land use and development planning.

The efficient use of water resources - necessary because of competition from other uses - and the prevention of soil and land degradation, are valuable contributions to the successful development of intensification and can contribute to easing the pressure on non-domesticated areas.

In general, these strategies, together with social and economic developments, can help satisfy future demands for food and contribute to eliminating hunger and malnutrition, while safeguarding the environment and fragile ecosystems. Based on the model-based assessment in this chapter, the following issues present a challenge to further research and international action.

Response options related to the scenario analysis

(i) In order to maximize food security, increasing agricultural productivity in a sustainable and sustained fashion remains an obvious but important challenge of governments, the agricultural sector, farmers and scientists.

(ii) Notwithstanding significant increases in productivity and land extension, developments as assumed in the Conventional Development scenario requires increasing imports from the North to the South. Additional analysis would be needed to evaluate the social, economic, environmental and political consequences of the findings in this chapter. Obviously, decreasing food security in major regions associated with a larger dependence on the world market may be a reason for political concern and responses.

(iii) Developing sustainable farming systems with high productivity and high ecological efficiency is only adequate to improve food security and to protect ecosystems if appropriate knowledge and methods are made accessible to all those who use and cultivate lands.

(iv) The assumed continuation towards the increasing consumption of food with a lower ecological efficiency, notably animal products, places an extra burden on agricultural production. A reduction in the consumption of animal products in industrialized countries and a slowing down of the increase in developing countries should be made a subject of research and debate.

(v) In so far as it reduces the degradation or destruction of natural ecosystems (for example forests, as indicated in the Forest Principles) agricultural development directed towards more intensive use of current agricultural areas can support existing ecosystem conservation.

(vi) The present analysis illustrates that in the next century suitable agricultural land will become increasingly scarce. This makes it even more important to halt land degradation and rehabilitate degraded lands, and not only in areas covered by the Desertification Convention.

The above specific responses can be seen as potential steps towards realizing or accelerating major transitions in the use of land and water as environmental resources. Chapter 7 returns to this concept.

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5 NATURE AND ITS DIVERSITY

5.1 The issue

Nature in all its diversity is under threat all over the world. In non-domesticated areas[1], population numbers and distribution of many species are experiencing a significant decline, leading to local or regional extinction and ultimately to irreversible global extinction. At the same time a small number of mostly opportunistic species are increasing substantially. According to the Global Biodiversity Assessment (UNEP, 1995), the extinction rate of animal and plant species since 1600 has been estimated to be 50 to 100 times the average estimated natural rate. Due to the projected forest loss over the next 25 years, the extinction rate is estimated to rise to between 1000 and 10,000 times the natural rate (UNEP, 1995).

The fact that in some locations 'species richness' as such may increase due to newly introduced species cannot compensate for the negative global effects (Figure 5.1). In domesticated areas[2] both wildlife and agricultural species, and their varieties, show a similar trend. In this chapter a global and regional assessment will be made of the extent to which future pressures may affect biodiversity quantitatively (area loss) and qualitatively (degradation of remaining area). Finally, some of the available options which may alleviate pressures are discussed.

5.2 The main causes of nature loss

Although specific causes may vary regionally, the relevant mechanisms resulting in the reduction and loss of populations, the extinction of species, and consequently the transformation and degradation of ecological communities include (UNEP, 1995):

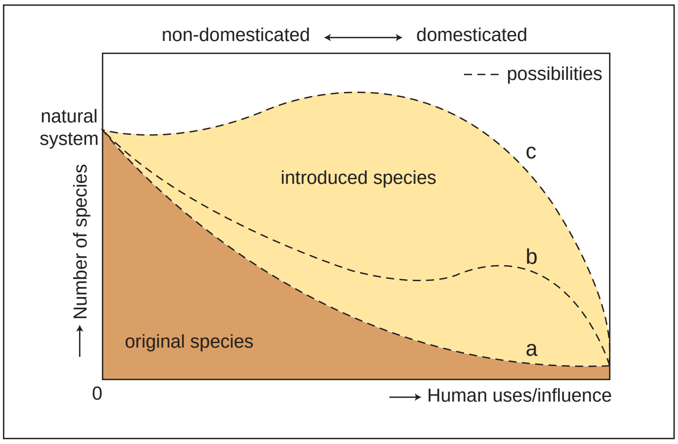

Figure 5.1. *The generalized relation between human influence and number of original species*

Note: Increasing human use generally results in a lower number of original species (a). Due to introduced species 'species richness' decreases to a lesser extent (b) or may even increase locally (c). Despite occasional increases of 'species richness' at the local level, a serious loss of biodiversity at the global level results.

[1] Non-domesticated land is defined here as all not human-dominated land, irrespective of whether it is pristine or degraded, such as virgin land, nature reserves; all forests except wood plantations with exotic species; areas with shifting cultivation; all freshwater areas and extensive grasslands (marginal land used for grazing by nomadic livestock). Note: the last-mentioned area is included in the figures for agricultural area in Chapter 4.

[2] Domesticated land is defined here as all human-dominated land such as arable land, permanent cropland, wood plantations with exotic species, pasture for permanent livestock, urban areas, infrastructure and industrial areas. Most domesticated land is in fact agricultural land.

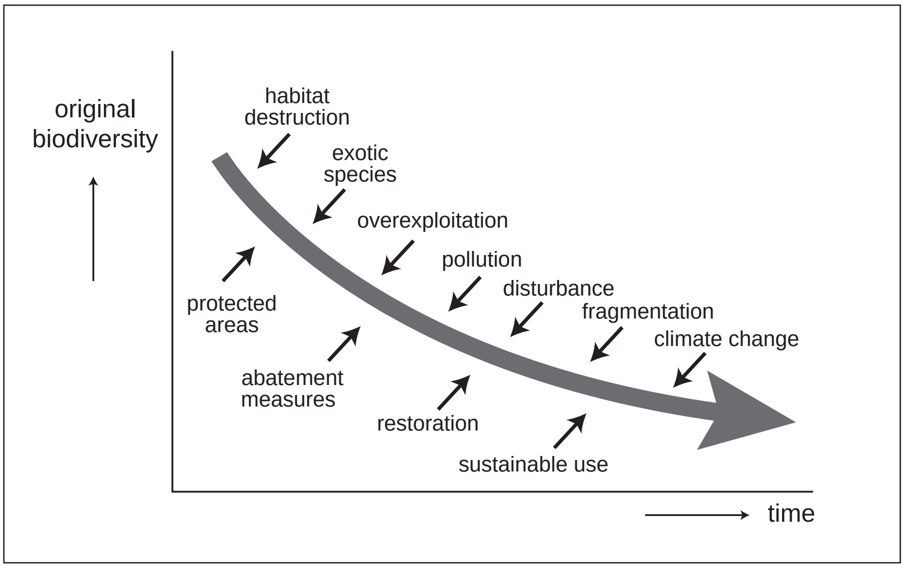

Figure 5.2. *Main causes of biodiversity gains and losses*

- habitat loss (e.g. conversion of land for agriculture, infrastructure, urbanization), fragmentation and degradation (see Chapter 4 on landuse changes);
- overexploitation;
- the introduction of non-native species;
- pollution and toxification of the soil, water and atmosphere (see Chapter 2); and
  climate change (see Chapter 3).

Positive factors are the establishment of protected areas, habitat regeneration and all measures which mitigate anthropogenic pressures (Figure 5.2).

5.3 The development of nature and its diversity

Past and present

Terrestrial ecosystems
Mainly as a result of the conversion of natural forests and grassland into cropland and pasture, the fraction of non-domesticated area decreased globally between 1700 and 1980 by one-third, from about 94% to about 64% (Figure 5.3). In densely populated subregions, such as the western part of Europe[3], the losses may have been considerably larger. Here, the remaining non-domesticated area is less than 30% (Kaales, 1996). In the Netherlands about 20% is left, of which 9% consists of terrestrial ecosystems (Van der Ven, 1996).

The total loss of global forest area[4] in the period 1700 - 1980 is estimated at one-fifth (from 47% of the global area in 1700 to 38% in 1980; Richards, 1990). Before 1700, considerable decline had already taken place in the temperate zones, especially from the Mediterranean basin to the Indus valley (ancient civilizations such as the Egyptian, Indian, Greek and Roman), in northern

[3] Europe excluding Scandinavia and Greenland.

[4] Forest and woodland.

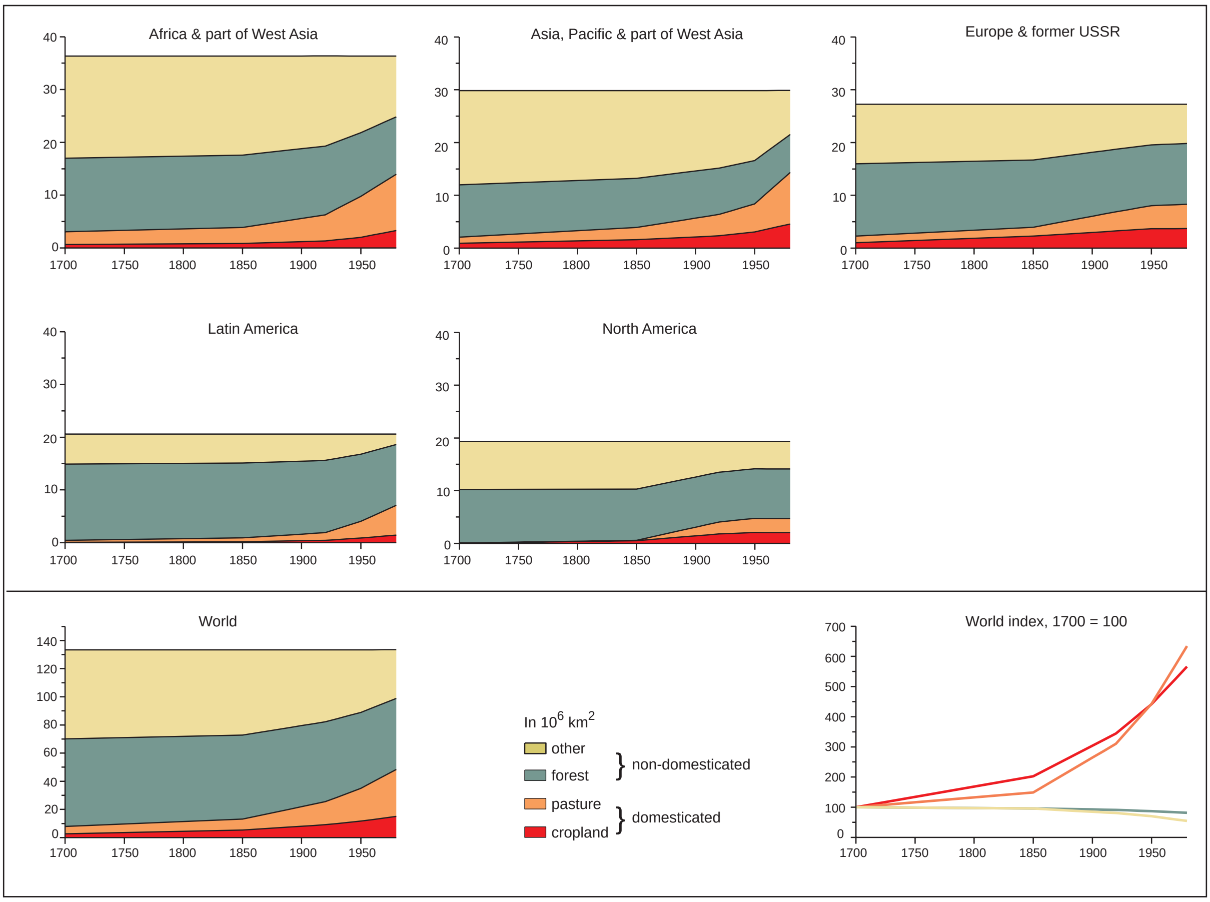

***Figure 5.3.** Historical habitat loss due to conversion from non-domesticated to domesticated area, 1700 - 1980*
Source: Klein Goldewijk and Battjes (1995), derived from Richards (1990) and FAO (1990)[5].

and northwestern China (FAO, 1995), and, in the middle ages, in north-western Europe (Idema *et al.*, 1993). In classical Greek and Roman civilizations forest was a major source of fuel, building materials and additional agricultural land. Even if forests were not cleared, the same result was produced by grazing, which also prevented natural regeneration (Mather, 1990).

While virtually all forests disappeared in the Mediterranean region after many centuries, in North America, where development started later in time, an initial rapid conversion of forested lands was followed by a slowing down and eventually stabilization and expansion of the forested lands, with a considerable amount of forest left. This spectacular reversal reflects a major transition from 'hunting and 'gathering' to 'farming' and conserving the forest resource within a 150 year period. In addition to changing demand and supply, also the changing perception of the forest resource with increasing value placed on recreation and wilderness qualities played a role. Moreover a climate of opinion that favoured increased governmental intervention and involvement in forestry matters arose (Mather, 1990).

Today the remaining cover of primary or old growth forest[6] is at the global level much less than the 38% mentioned above. Primary forest cover has been greatly reduced in most industrialized

5 For the current situation, figures of the same order of magnitude have been found for the globe by Hannah *et al*. (1994) and for Indo-Malayan and Afro-tropical nations by Mackinnon and Mackinnon (1986a, b). Differences can be explained by different definitions of habitat loss and different divisions in regions.

6 Forests more than 200 years old.

countries, and is rapidly decreasing in the developing countries. In Western Europe, the forest area is about 1% old-growth forest, in Scandinavia about 2%, in China about 1%, in the USA about 15%, in Canada about 52%, and in New Zealand about 25% (Dudley, 1992). In developing regions, the average annual decline in forest area (forest and other wooded land) between 1980 and 1990 was 0.43 per cent, but the loss of natural forest area was 0.8 per cent per annum (FAO, 1995). The histories of the Mediterranean region (a negative example) and North America (a positive example) mentioned above illustrate the different patterns of forest use that countries could expect in the near future, depending on the approach they follow.

The remaining non-domesticated areas also suffer from loss of ecosystem quality due to various pressures. For example, forests are losing vitality due to acid rain in parts of Europe, Asia (Chapter 3) and North America (NAPAP, 1991). Similarly, freshwater ecosystems suffer from habitat loss and various pressures such as pollution, overexploitation and canalization. Both the loss of area and quality lead to considerable decline in the distribution and/or population numbers of many plant and animal species.

Marine ecosystems

Although the extent of marine ecosystems has not changed, many populations of species have changed because of human activities, such as overexploitation of fish stocks and whales. Up to 1970, the world catch of marine fish had continued to rise at an overall rate of some 6% per year. In the early 1970s this slowed dramatically and between 1980 and 1989 the overall rise was down to around 2.3% annually. The first decline since 1976 came in 1990, with a drop of some 3% (FAO, 1993).

Figure 5.4 shows the current state of major exploited fish stocks in the Pacific and Atlantic Oceans. Although natural fluctuations are important, overexploitation is a common factor that accounts for both past and current low levels of stocks. In response to decreasing yields from conventional stocks, fishing fleets have been moving to new fishing grounds and to other, mostly small species with a short lifespan, which are generally of a lower economic value. Meanwhile, the global industrial fleet size has increased at a rate double that shown by global landings over the period 1970-89. The negative consequences of this may be just as serious from an economic as from a resource perspective. It has been reported that the total annual operating costs of the global marine fishing fleet in 1989 were considerably higher than total revenues, even without

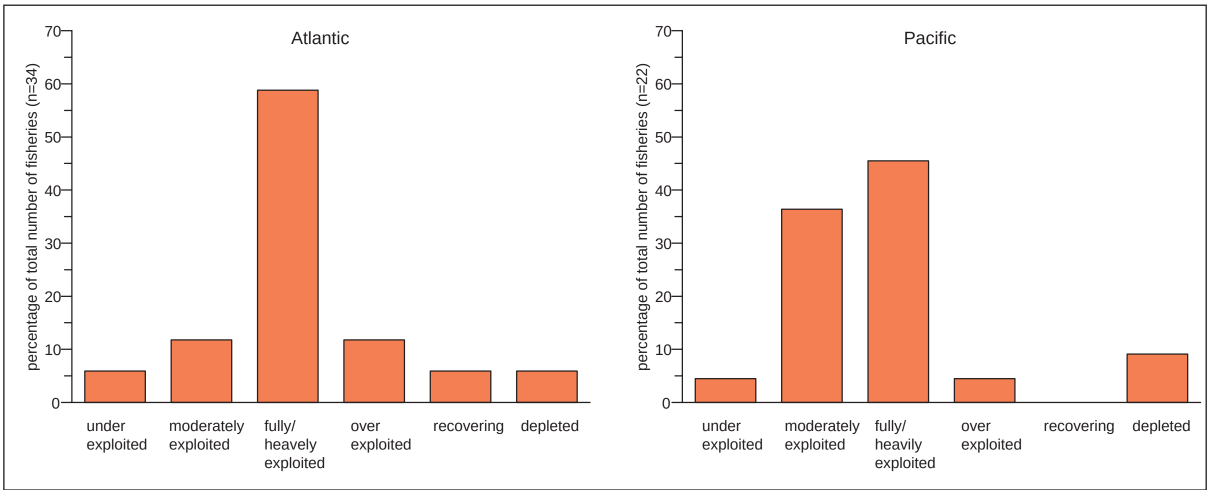

__Figure 5.4.__ States of exploitation of major fish stocks

Note: This relates to stocks with at least once a catch of more than 100,000 ton per year.

Source: FAO (1993).

considering capital costs (COFI, 1993). Continued fishing at this level of intensity will contribute to a loss of biological diversity and there are fears that this may lead to less stable, and possibly even lower, catches in the long term (FAO, 1993).

Marine mammal resources are among the most vulnerable to over-fishing because of their slow growth and low fecundity. In particular, unrestrained whaling severely reduced many stocks in the eighteenth and nineteenth centuries and nearly eliminated all species of large whales early in the twentieth century, providing one of the best examples of non-sustainable development in the history of fishing. With the exception of the Minke whale, the Grey whale in the eastern North Pacific and Bryde's whale in some oceans, large whales have been seriously depleted, in some cases perhaps beyond the level of recovery. The final Revised Management Procedure, adopted in 1992, calls for protection of stocks reduced below 54% of the pre-exploitation level (FAO, 1993). Figure 5.5 shows the current estimated state of various whale populations.

Coastal zones

In addition to the pressures on specific commercial species, coastal ecosystems are at risk due to a range of development-related pressures. It is not yet possible to give global indications of the state

Figure 5.5. *State of various whale populations compared with their estimated original state*
Source: Hilborn (1990).

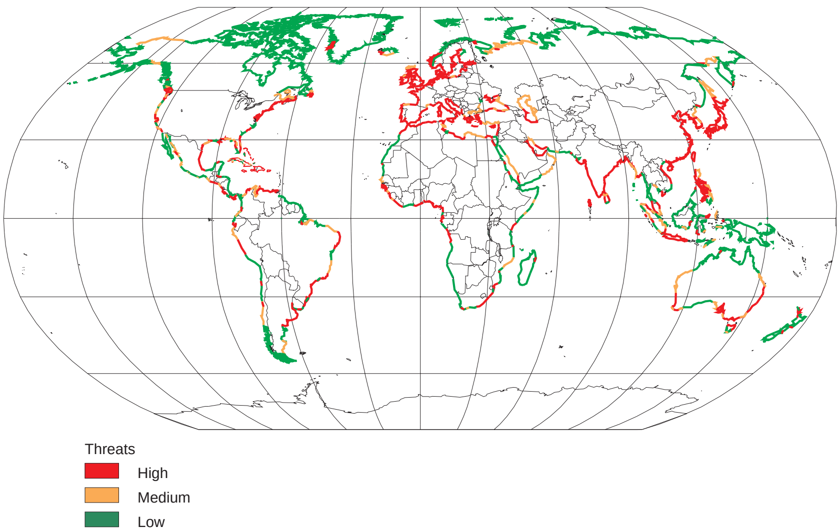

Figure 5.6. *Coastal ecosystems threatened by development, in particular population density, road and pipeline density, cities and major ports*
Source: Derived from Bryant *et al*. (1995).

of these ecosystems. However, based on the known pressures, Bryant *et al*. (1995) found that 17% of the world's coastline was at medium and 34% at serious risk due to high population density, roads, pipelines, cities and major ports (Figure 5.6).

The future

What changes in extent and distribution of non-domesticated areas may be expected in the coming decades? And to what extent will the quality of the remaining habitat change due to various pressures? Projections of the extent and distribution of non-domesticated areas have been made with the IMAGE 2.1 model, based on the Conventional Development scenario (Figure 5.7, Table 5.1 and Figure 5.8). These are consistent with the projections of landuse changes in previous Chapters.

As to the quality of ecosystems, increasing production and consumption, along with population growth, will generally increase pressures on the remaining non-domesticated area (UNEP, 1995).

Table 5.1 *Projected extent of non-domesticated land.*

	1990	2015	2050	change
	% of regional area			
Africa	70	55	45	- 25
Asia & Pacific	60	50	55	- 10
Europe & former USSR	75	75	70	- 5
Latin America	70	65	60	- 10
North America	80	80	80	spatial shift
West Asia	90	75	70	- 20
World	70	65	60	- 10

Note: Rounded off to 5% intervals.

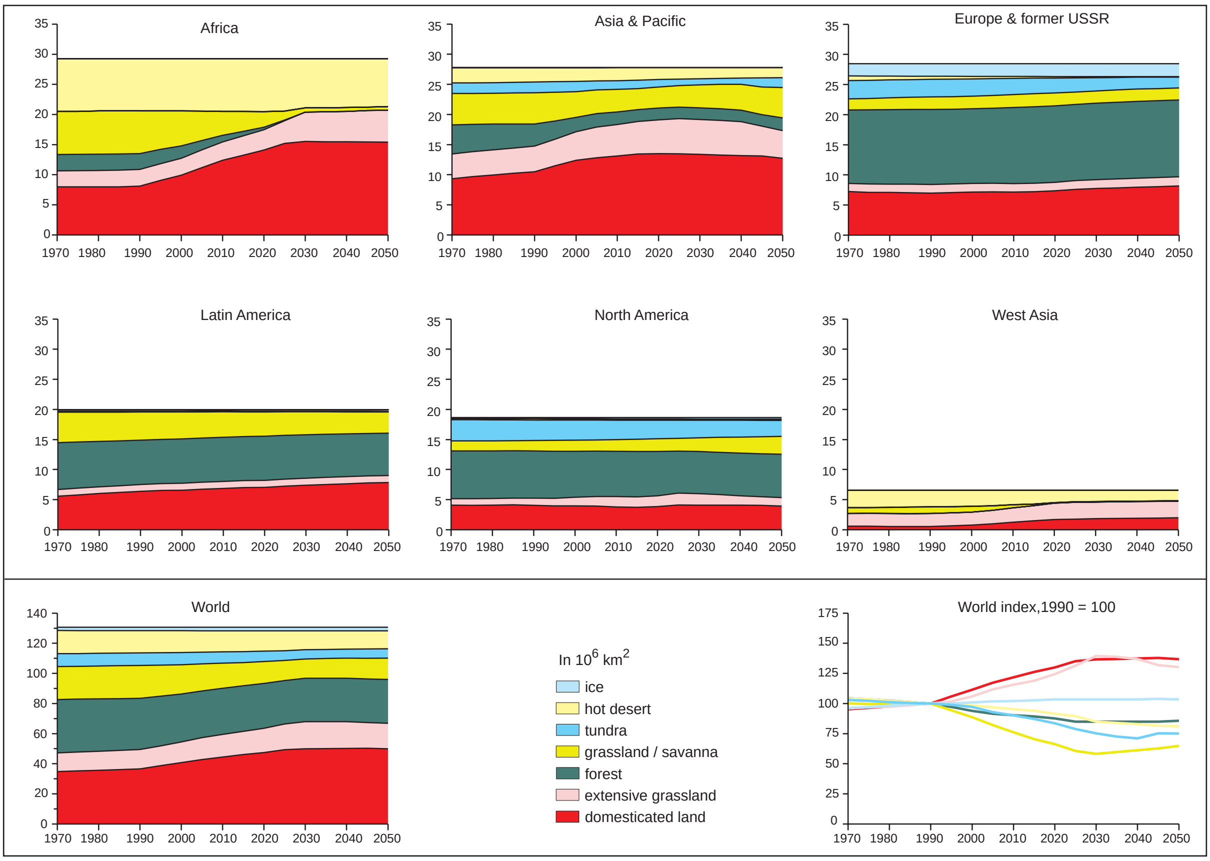

Figure 5.7. *Projected extent of non-domesticated area[7], 1970 to 2050[8]*

For the present study, the projected changes in four consumption- and population-related pressures have been projected on a spatially detailed basis. These pressures are: i) 'population density', ii) 'consumption and production rate', iii) 'forest clearance for timber' and iv) 'climate change'[9]. The results, aggregated by region, are shown in Figure 5.10. It is assumed that the total pressure[10] and the extent of the remaining area will provide an indicative picture of the 'biodiversity at risk': the smaller the remaining non-domesticated area and the higher the pressures on this area, the higher the chance of poor biodiversity quality[11] (for a technical explanation see also Appendix III).

7 The marginal land used for grazing (extensive grasslands) is defined here as 'non-domesticated'. However, in Chapter 4 this has been defined as part of the 'agricultural land'. Therefore the figures from Chapter 4 and 5 can not simply be added.
The Figures 5.3 and 5.7 differ for 1970-1980 because two different sources are used, with slightly different regions and definitions for the underlying categories, such as extensive grassland, forest and pasture. In Figure 5.3, West Asia is divided over Africa and Asia & Pacific. More important than the absolute figures are the changes.

8 Forest here refer to all forests, including tropical woodland and regrowth forest. Grassland/savannah here includes grassland, steppe, scrubland and savannah and excludes extensive grassland. Extensive grassland here includes all (marginal) land used for grazing. Tundra here includes tundra and wooded tundra.

9 These pressures have been chosen because they could be roughly modelled on the regional and global scales, and appear to be important factors in the degradation of ecosystems and their biodiversity.

10 The pressures considered are determined for each non-domesticated IMAGE grid cell and preliminarly rated on a simple linear scale from 0 (no pressure) to 10 (very high pressure). For each pressure level, a value of 10 is expected to have a high chance of poor biodiversity quality compared with the original state. The total pressure is preliminarly calculated by simply aggregating these four pressures per grid cell. In practice, the impacts of various pressures will probably be non-linear. See also Appendix III.

11 A similar, pressure-based, approach is applied by Hannah *et al*. (1994) and Bryant *et al*. (1995). For future GEOs this simple approximation of the quality of nature at risk needs to be further elaborated and scientifically underpinned. In the longer term, this indirect pressure indicator should be replaced with or complemented by direct state indicators.

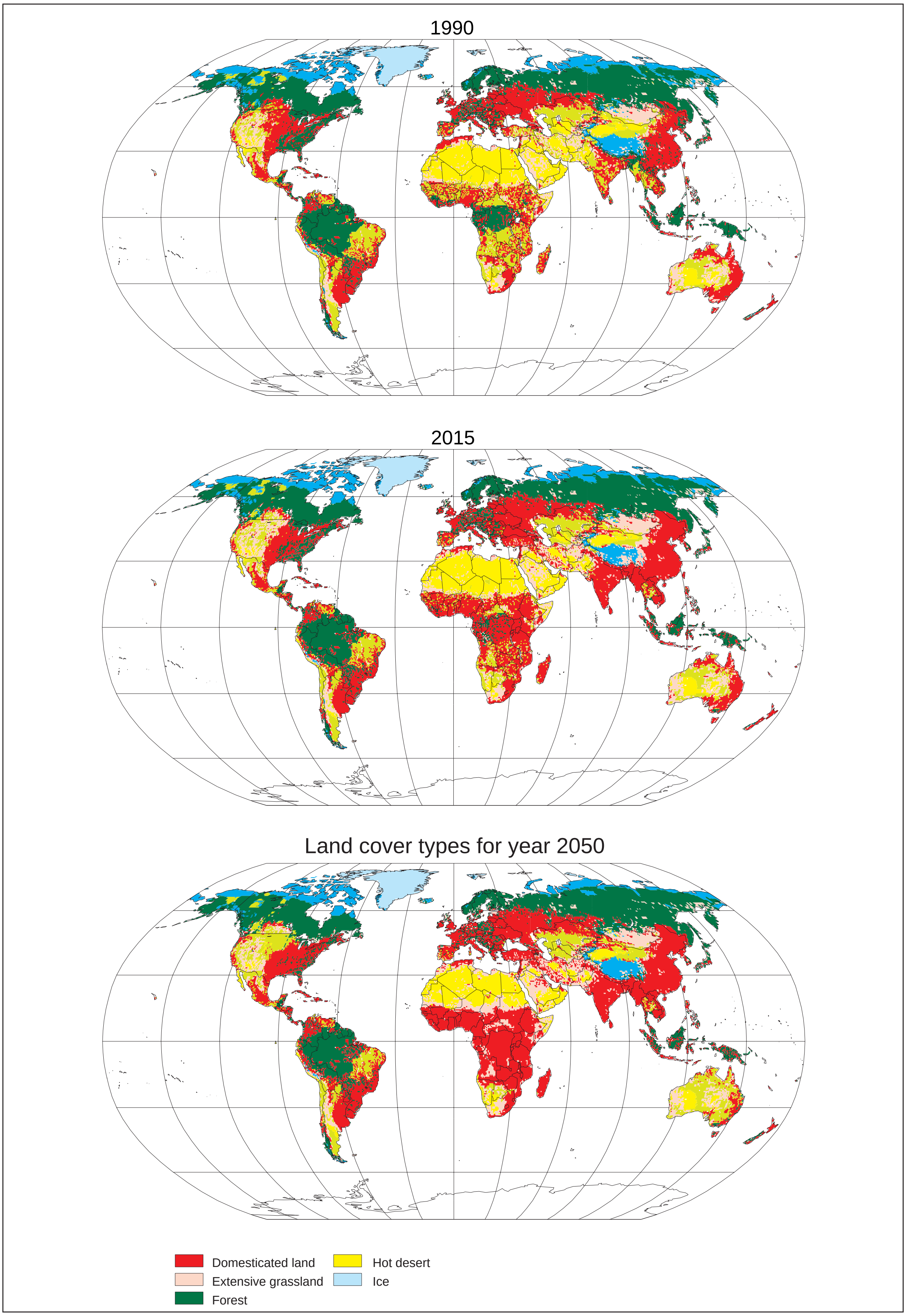

Figure 5.8. *Spatial distribution of the main non-domesticated areas projected according to the assumptions of the Conventional Development scenario*

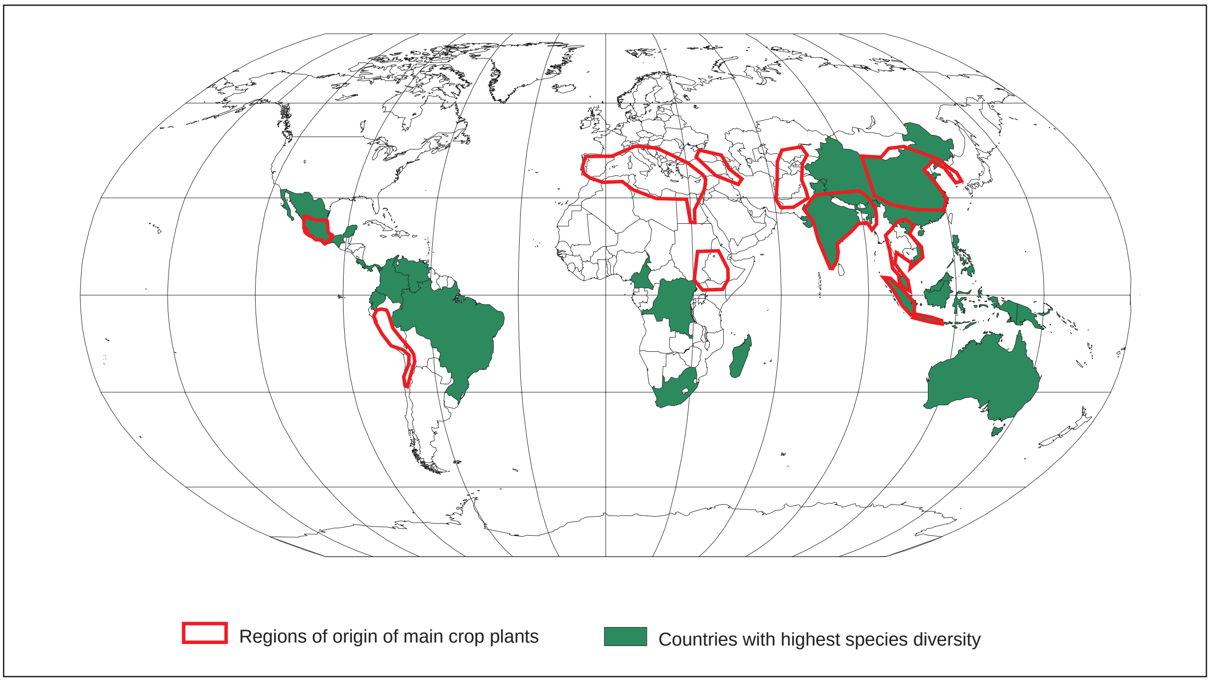

Figure 5.9. *Spatial distribution of the main origins of crop plants and the 20 countries with highest species diversity*
Source: WCMC (1992) adapted from Hawkes, (1983/1991); WCMC (1994).

The calculations on change in extent of non-domesticated area and pressures as shown in Figures 5.7 en 5.10 lead to the following findings:

- Africa's non-domesticated area, especially forests and grassland/savanna, will largely be converted to agricultural land, implying a decrease in non-domesticated area from the current 70% to about 55% in 2015 and 45% in 2050. Grassland/savanna, which has so far been mainly open rangeland, will largely be converted to permanent pasture (domesticated area). In the scenario, forests will, to a large extent, disappear. The remaining non-domesticated area will be mostly arid and semi-arid and include area used for extensive grazing (Figures 5.7 and 5.8).
  The sum of the four pressures considered on the remaining non-domesticated area will, on average, double in intensity, reaching a high level (from about class 2 to 5). Of these pressures, climate change is dominant (Figure 5.10). Moreover, the area used for extensive grazing ('extensive grassland') is also doubling, providing an extra pressure on the remaining non-domesticated area (Figure 5.7).
  Consequently, according to the scenario, Africa's nature is at very high risk, both in quantity and quality.

- The non-domesticated area of Asia and the Pacific is projected to decrease from the current 60% to somewhat more than 50% in 2015 and slightly increase to 55% in 2050, mainly due to the expansion and subsequent regression of arable land. By 2015 and 2050 the forest area will be further reduced from the current 12% to about 7% of the total area, about one-fifth of the 35% of forested land area[12] in 1700 (Richards, 1990). The remaining non-domesticated area, less suitable for human settlement and agriculture, is largely found in mountainous areas or (semi-)arid zones.

[12] This figure is differently defined and is not entirely comparable with those used for present and future.

Table 5.2. *Projected percentage of non-domesticated area under different degrees of pressure from the human population and associated activities*

		pressure class				
		low	moderate	high	very high	extremely high
		Per cent of regional land area				
Africa	1990	18	25	1	0	1
	2015	0	20	23	1	1
	2050	0	15	26	2	2
Asia & Pacific	1990	10	28	3	1	4
	2015	1	15	23	2	7
	2050	1	14	22	2	8
Europe & former USSR	1990	18	43	4	2	4
	2015	5	20	36	4	7
	2050	5	19	35	4	9
Latin America	1990	38	17	3	1	1
	2015	23	20	14	2	2
	2050	18	21	15	2	4
North America	1990	13	49	7	1	2
	2015	6	15	39	7	5
	2050	6	14	37	7	9
West Asia	1990	5	44	14	4	3
	2015	0	4	41	11	13
	2050	0	0	30	16	24
		Per cent of global land area				
World	1990	18	33	4	1	3
	2015	6	17	27	3	5
	2050	5	16	27	4	7

Note: Total pressure is expressed as ranging from low (0-2), moderate (3-4), high (5-7), very high (8-10) to extremely high (>10). See Appendix III for further details. The pressure is calculated for areas which are non-domesticated during the whole period from 1990 - 2050.

In many Asian countries, the area of agricultural land is currently fairly stable. In the scenario, continuing economic and population growth leads to higher demands for food that are met primarily by intensification of agriculture, partly by further land expansion, and partly by increasing imports. Higher intensification or increasing imports lead to lower conversions.
The pressure on the remaining non-domesticated area will in this scenario increase, on average, by 50%, from a moderate to a high level (from about class 3 to 5). From these pressures, climate change and to a lesser extent, population density are the dominant pressures. Next, the area used for extensive grazing ('extensive grassland') increases 25%, posing an extra pressure on the remaining non-domesticated area.
Consequently, according to the scenario, Asia & Pacific's nature is at high risk.

- Europe's and former USSR's non-domesticated area is projected to be fairly stable until 2015 and slightly decreases from the current 75% to more than 70% in 2050, mainly due to increased food exports from Europe. The non-domesticated area is to a large extent situated in the former USSR and the Nordic countries.

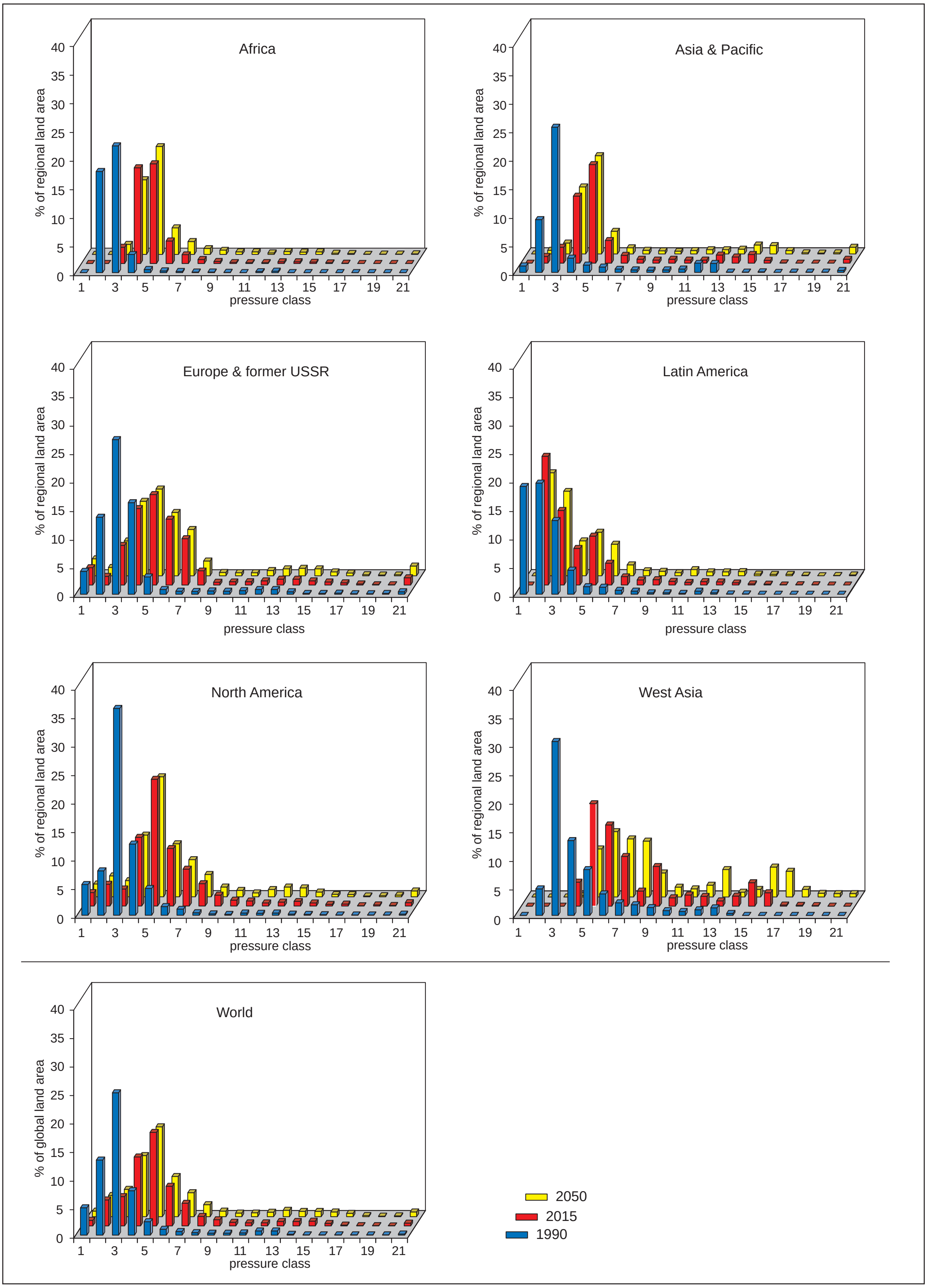

Figure 5.10. *Projected percentage of non-domesticated area under different degrees of pressure from the human population and associated activities*

Note: Total pressure is expressed as ranging from low (0-2), moderate (3-4), high (5-7), very high (8-10) to extremely high (>10). See Appendix III for further details. The pressure is calculated for areas which are non-domesticated during the whole period from 1990 - 2050.

The pressure on the non-domesticated area will, on average, almost double in intensity up to a high level (from more than class 3 to 6). Climate change is the dominant pressure.
According to this scenario the natural areas of Europe & former USSR are at moderate risk, especially due to climate change.

- Latin America's non-domesticated area is projected to decrease from the current 70% to about 65% in 2015 and 60% in 2050.
  The pressure on the remaining non-domesticated area will, under the assumptions of the scenario, double on average in intensity from the present low level to a moderate level (from about class 2 to 4). Climate change, and to a lesser extent, population density are the dominant factors. The factor climate change will especially affect the temperate zones.
  According to this scenario the natural areas of Latin America are at relatively moderate risk in comparison to Asia and Africa because of their relatively low population growth and projected increase in agricultural production through intensification. If colonization of the Amazon were to be continued, or if socioeconomic problems are not ameliorated, more rapid and extensive conversion of forest may occur than in this scenario.

- North America's non-domesticated area is projected to fluctuate by a few per cent around 80% from 1990 to 2050. However, a considerable shift of non-domesticated area from the east to the midlands is expected due to climate change. The forested areas in the east are expected to be converted to arable land, while the arable land in the midlands will be reconverted into (extensive) grassland. In 2050, the greater part of the non-domesticated area is situated in the mountainous west, dry midlands and in the boreal and subpolar north.
  The pressure on the remaining non-domesticated area will, on average, double in intensity up to a high level (from about class 3 to 6); this is largely due to climate change. According to this scenario, natural areas in North America are at moderate risk due to climate change and the expected spatial shift.

- West Asia's non-domesticated area is projected to decrease from the current 90% to about 75% in 2015 and 70% in 2050. Grassland/savanna, which has so far been mainly open rangeland, will be largely converted to permanent pasture (domesticated area). The remaining non-domesticated area will be mostly arid, semi-arid and be used for extensive grazing.
  The pressure on the remaining non-domesticated area will, under this scenario, double on average in intensity to a very high level (from about class 4 to 9). Population density, and to a lesser extent, climate change are the dominant pressures. Moreover, the area used for extensive grazing ('extensive grassland') will increase by one-third (about 30% to 38% in 2015 and 40% in 2050), providing an extra pressure on the remaining non-domesticated area.
  Consequently, according to the scenario, natural areas in West Asia are at very high risk, both in quantity and quality.

- The world's non-domesticated area is expected to decrease from the current 70% to about 65% in 2015 and 60% in 2050. Although this change appears to be small at first sight, many specific species-rich ecosystems in the tropical and subtropical zones (Figures 5.8 and 5.9) are at serious risk, especially due to conversion to agricultural land. In the 20 countries with highest species diversity (WCMC, 1994) about 25 per cent of the current non-domesticated area will be converted until 2050. Very much of the world's remaining non-domesticated area is situated in mountainous, boreal/subpolar, arid and semi-arid zones, generally less suitable for human settlement. Consequently, the per capita non-domesticated area declines from the current 1.8 ha to 1.1 ha in 2015 and 0.8 ha in 2050 (Figure 5.11).
  The pressure on the remaining non-domesticated area will, on average, roughly double from a moderate to a high level (from class 3 to almost 6). This is largely due to climate change,

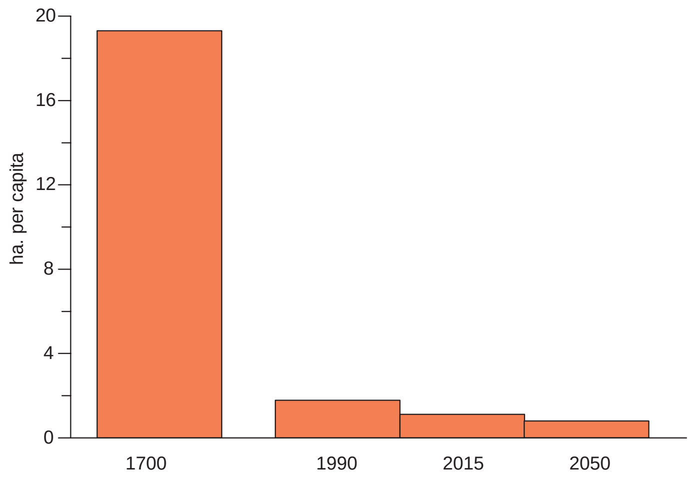

Figure 5.11. *Historical and projected per capita non-domesticated area*
Note: The distances between bars represent unequal lengths of time.
Source: Klein Goldewijk and Battjes (1995) (past) and calculations of IMAGE 2.1 based on the Conventional Development scenario (projections).

particularly in the northern temperate and boreal zones, and is to a lesser extent due to population growth, particularly in the southern regions. Moreover, the area used for extensive grazing (‘extensive grassland’) will increase by almost one-third (about 10% to 12% and 13%), providing an extra pressure on the remaining non-domesticated area.

- According to the scenario, the world’s centres of origin of the major crop plants (Figure 5.9) will become further domesticated, from about 45% in 1990 to 60% in 2015 and 65% in 2050. Further, the average pressure due to climate change will increase by two-thirds (from about class 3 to 5). The centres of origin of the major crop plants are of particular interest for the world’s future food security.

Consequently, according to the scenario, the world’s natural areas are at serious risk. Processes leading to further degradation of natural habitats and biodiversity are in progress all over the world.

5.4 Discussion

Assessing effects on nature and its diversity is not an easy task, certainly not on the scale we are dealing with here. The most severe handicaps are reliable and standardized data, unambiguous definitions and generally accepted indicators and assessment frameworks, analogous to those available for economic assessments for decades. Moreover, in addition to the pressures considered in this analysis, there are many other factors affecting nature, such as pollution, overexploitation and introduction of exotic species. Therefore the results must be seen in the limited scope of the present analysis.

For this reason this is to be seen as a preliminary assessment, based on the data, knowledge and models which are available to date on the global scale. The effects on nature or biodiversity are predominantly assessed by quantifying the changes in terms of area and the pressures on the remaining natural habitat. In future assessments for GEO, it is intended to pay more attention to the state of ecosystems as such, to fresh water and marine ecosystems, and to biodiversity in domesticated areas and to biodiversity use. Also, more local pressures and conservation measures should be incorporated. These might be as important as the four pressures considered here. Therefore a regional approach should be adopted. For this purpose a limited core set of indicators for biodiversity and its uses is being proposed (Ten Brink and Douma, 1995) which is intended to be further developed in cooperation with regional institutes. This indicator development will be matched with other frameworks currently being developed, e.g. the Convention on Biological Diversity. In the short term, it is intended to simultaneously further elaborate and underpin a pressure-based approach.

It is not intended to provide a detailed picture of the state of biodiversity as such in the GEO reports. This is primarily the goal of the National Biodiversity Studies in the context of the Convention on Biological Biodiversity. GEO aims to provide a necessarily general overview of changes in biodiversity at the regional and global levels, as function of various social and economic scenarios.

5.5 Response options

Under the Conventional Development Scenario, leading to the above projections, it is unlikely that the objectives of the United Nations Convention on Biological Diversity will be met ('*the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits*'). The loss of biodiversity appears to be continuing into the next decades. If we want to stop this process, a transition would be needed in our approach to nature. However, formulating the required mitigating and adaptive responses will not be easy, since the main underlying mechanisms comprise powerful driving forces. An integrated, cross-sectoral approach appears to be essential. Landuse planning might be an essential instrument in safeguarding nature. The following findings with respect to responses can be derived from the present analysis:

(i) economic and demographic transitions in addition to nature protection

The analysis in this chapter underlines the important impact on biodiversity of projected climate change and of economic and population growth, along with the associated need to convert non-domesticated land to agricultural land in order to satisfy food demands. Remaining natural habitats can only be protected effectively if appropriate measures are taken to allow increased agricultural production by means other than the conversion of natural lands, and by providing farmers with viable development alternatives. Understanding transitions is important to finding solutions, as illustrated by the historical examples of the Mediterranean and North American forests.

(ii) linking remaining natural areas

Although protection of areas, for instance, in nature reserves, appears to be a prerequisite for conserving nature and its diversity, climate change will be a serious threat. It is estimated that climate change would change the potential vegetation in 44% of the world's current conservation areas. Migration is a common response of many species to climate change, so connections between natural areas are a prerequisite for mitigating biodiversity losses. Consequently, the current natural vegetation in these areas will not be able to adapt to these changed climate conditions if these areas are isolated and fragmented (Alcamo *et al*., 1995). The design of *'Regional Ecological Networks'* of interconnected natural areas (that is, linking remaining natural areas) might be an efficient response to this problem. Incorporating mountainous areas where vertical migration is possible might be particularly effective in this respect. This is intended in the Middle America Biological Corridor GEF project, which is currently in its preparatory phase. This illustrates the interdependence of countries in their efforts to conserve their biological diversity.

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6 EFFECTS ON HUMAN HEALTH

6.1 The issue

Over the last five decades, most populations of the world have experienced an enormous and continuing improvement in health. At the same time, there are poignant regional and national exceptions. There have always been and always will be environmental factors[1] that have a negative effect on health. Their influence on the occurrence of human diseases and deaths in these 50 years has been decreasing, but for the future there is a possibility that the occurrence of especially infectious diseases will increase (WHO, 1996). Will the present situation deteriorate too if future increases in population sizes and composition, and consumption levels (related to improved health), lead, as described in the previous sections, to disturbance in the atmosphere, land, water and biological resources? As demonstrated at the local level, environmental factors such as pollution can have direct negative effects on human health; other environmental factors can also pose an indirect threat to health by reducing the availability of food and water in some large areas of the world.

This section will address three main questions. First, what are the main determinants of human health and what is the relative importance of environment-related determinants? Second, how will the state of health for the world populations develop and how does that relate to the assumptions in the Conventional Development scenario? And third, what can be done to improve health in terms of loss of (disability-adjusted) life years[2] and how effective are environment-oriented responses designed to achieve this? The innovative aspect of the approach adopted here is that (1) it combines both population and health dynamics and (2) that it includes the main broad determinants of fertility and health.

6.2 The relative importance of health determinants

A number of both negative and positive health determinants can be distinguished (Table 6.1). These factors are included in the TARGETS model[3] used to explore possible future scenarios on changes in health determinants during the health transition of the world's populations. The health transition approach addresses changes in population and health change in one general frame of reference. (see e.g.: Caldwell, 1993; Frenk, 1993; Ness, 1993). It describes how populations may go through typical health and fertility stages (Figure 6.1) as they change from living in pre-industrial environmental conditions to those of post-modern societies. The health transition has two components: an epidemiological transition, determining death rates and a fertility transition, determining birth rates. The health transition is defined as including the changes in these two areas, as well as the concomitant changes in the environment and organization of social and health-related services. The resulting combined effects on population size and structure is labeled as the demographic transition. The epidemiological transition shows a shift from a situation in

1 Environment is defined broadly here to include the availability of food and water in sufficient quality and quantity, the presence of pathogenic microorganisms, as well as local geographical, physical and chemical factors. The environment, together with individual genetic make-up and behaviour, is seen as one of the major determinants of health (Cartledge, 1994).

2 DALYs (Disability Adjusted Life Years) are a measure of years lived subtracting an estimated percentage for each year lived in incomplete health (assessing complete health as 100 %).

3 TARGETS is a model being developed at the RIVM to analyze issues related to sustainable development at a global level (Rotmans and de Vries, 1997). A preliminary version of one of its submodels, the health model, is used to illustrate some of the

which environment-related infectious diseases at a young age are dominant to a situation in which the occurrence of diseases are postponed until the last years of life. The resulting average life expectancy at birth can rise from around 30 to over 80 years of age. In the last life stages the chronic diseases are dominant. In these stages environmental factors may influence one's surviving a number of chronic diseases (IPCC, 1996) The fertility transition describes the decline of the fertility level. The change in fertility behaviour is generally seen as being caused by the process of modernization within societies. The fertility level, represented by the total fertility rate, can be in the process of dropping from 7 children per woman in the early stages of the transition to 4.9 or even far below, a replacement level of 2.1 children per woman.

The health transition can be categorized by the three stages of combinations of the epidemiological and fertility transition as shown in Figure 6.1. They are:
Stage 1: Reproductive health needs and mainly environment-related risks of diseases in the early stages of the health transition.
Stage 2: Continuing reproductive needs and health risks in populations in the midst of the transition with a growth in population size and competition for resources.
Stage 3: Health needs of aged populations that have reached a presumably new steady state, with a zero population growth where fertility is controlled and survival improved.

The importance of the roles of both *public health interventions* and *curative medicine* in improving health has been, and often still is, overestimated for some time (Boxes 6.1 and 6.2).

Many health problems have not been solved exclusively by medical means, and at present the most successful approaches are mainly multi-disciplinary. At least, several explanations of observed improvements in health are open in most cases.

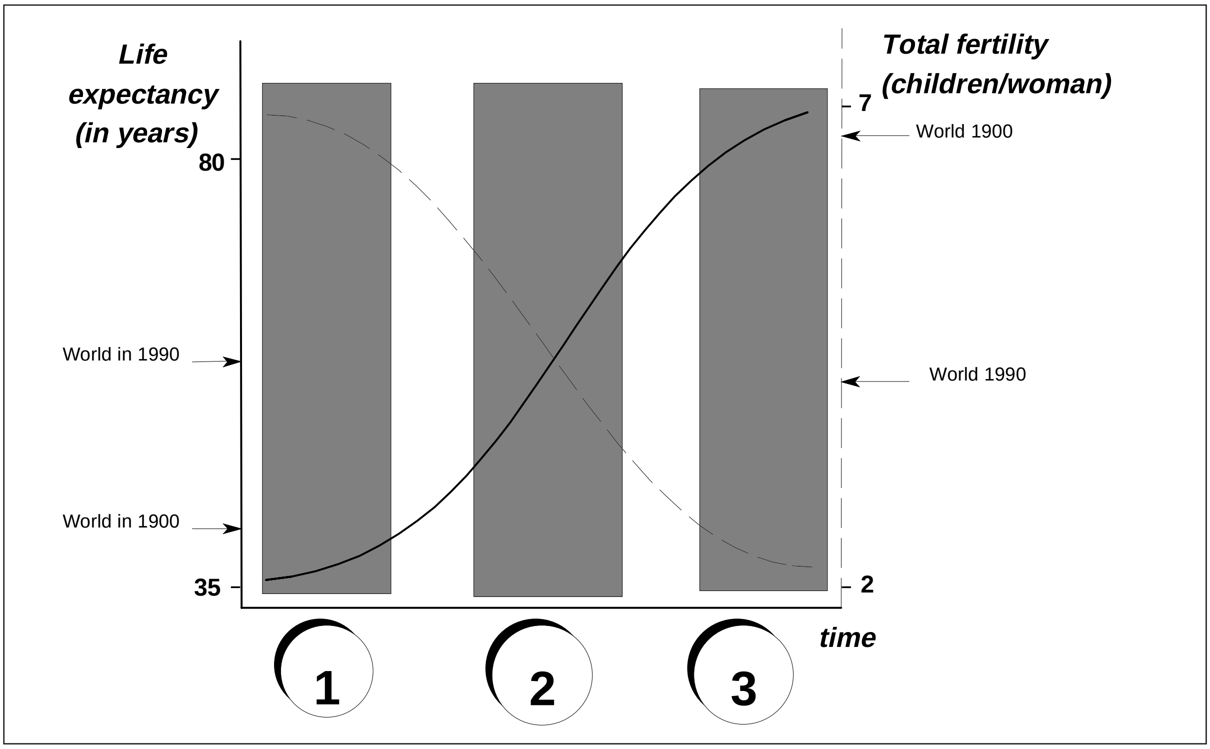

Figure 6.1. *The three stages of the health transition*
Note: The left y-axis represents life expectancy and the right y-axis level of fertility. The figures are for the world population as indicated.
Source: Niessen and Hilderink (1996).

Table 6.1. *Selected factors affecting health for most world populations in the first two stages of the health transition*

Negative	Positive
illiteracy	literacy
low economic status (not in all aspects)	high economic status (not in all aspects)
malnutrition	sufficient food of good quality
lack of appropriate health care	good and accessible health care
water deficient in quantity and quality	enough safe water
no sewage control	sewerage systems
polluted air	clean air
degraded ecosystems	ecosystems sustained

note: See also figures 6.1 and 6.2.
Source: Frenk *et al*. (1993).

For instance, in the case of certain waterborne diseases, preventive medical intervention can take the form of either water hygiene or a vaccination programme (i.e. source elimination versus immunization of the potential victims). However, although safe water can prevent more than one disease, it is not implied to be necessarily and automatically the only solution. Indeed, because of the availability of some highly effective vaccines at low cost, developing countries may often have several options open to them. And it should be noted here as well that the precise impact of vaccination programs will differ depending on a country's stage in the health transition. Vaccination can have a relatively significant influence in countries in pre- and early transitional stages, while even large-scale medical efforts will only impact marginally on health indicators in countries in late transitional stages (WHO, 1993; Van der Velden *et al*., 1995).

The importance of *water sanitation, storage, supply and sewage systems* as health determinants has been the subject of extensive studies. The outcomes have shown that improved water supply and sanitation facilities do not automatically lead to a decline in disease and death levels. Because the etiology (causal factors and their interactions) of many diseases is so complex, these measures cannot in themselves always be expected to be immediately successful (Pollitzer, 1959; Cairncross and Feacham, 1983)[4]. Recent studies following activities with satisfying results, in which safe water has received much attention, show that a reduction of disease in poor city quarters in developing countries of about 25 per cent can be achieved, mainly by hygienic measures other than safe water (2/3 versus 1/3 of the 25 per cent) (World Bank, 1993).

Box 6.1 *Improvements in health preceded modern medicine*

As McKeown (1976) has thoroughly demonstrated, much of the improved health and increased life expectancy in developed countries occurred during the period up to approximately 1900. In this period medicine had hardly any influence - certainly in the field of communicable diseases. For instance, in the Netherlands, life expectancy increased from an average of 35 years in 1845 to an average of 55 years in 1910. Medical science had only an indirect influence on this development by way of the struggle of the hygienists for safe water and sanitation services. In the subsequent period, up to 1990, 20 years life expectancy were added on - and this time with significant medical influence (e.g. vaccinations, antibiotics) (McKeown, 1976).

[4] The introduction of water distribution in Dutch towns in the 1870s and 1880s was in itself not sufficient to prevent the dreaded *Salmonella typhi* infections. Farmers still contaminated the milk by rinsing the milk containers in ditches and town dwellers continued taking drinking water from canals (for the taste). Moreover, family members continued to spread this fecal-oral infection in their households.

Box 6.2 *Health development and a multitude of pressures*

In most developing countries there is obviously occurring an epidemiological or 'health' transition is obviously occurring. The comparative importance of the role of medicine in this transition is even more difficult to assess than its historical role in the now developed countries. This is because all changes in health determinants are presently coinciding, thus confounding the impact of isolated health determinants. Not only are the several factors (education, vaccinations, transport, sanitation, nutrition, etc.) in a kaleidoscopic interaction, but developments take place much faster than in, for instance, Sweden (more than 200 years) or the Netherlands (more than 100 years). In this fast leap forward some disciplines tended to overestimate the impact of their specific efforts (McKeown, 1976; WHO 1993).

It is for this reason that it is necessary to evaluate the importance of *education, insight and rational behavior* as health determinants. These factors continue to be underestimated in proportion to their enormous impact, both past and present. Restrictions in the supply of clean water and in the availability of food (both in quantity and quality) can be detrimental to health, but this influence can be strongly mitigated by good management. Of course, the *combination* of a favourable economic situation (income) and a high educational level will be most effective in overcoming the negative effects of water or food of poor quality[5].

The aforementioned impact of *economic situation* and *income* on health is far reaching. Direct influence is exerted by the ability to finance health-improving goods and services; indirectly many factors like education are strongly linked to national and individual prosperity. Welfare can also have negative influences on health; examples are high caloric intake, e.g. saturated fatty acids, and little exercise[6].

The health effects of *environmental factors in a broader sense, such as food and water availability (or shortages)*, remain a complex problem. Despite the fact that famines and malnutrition remain local threats, the food problem at the global level according to the Conventional Development scenario is not a matter of sufficient production but of regional distribution (see Chapters 2 and 4). Even with a relatively limited expansion of arable land, the

Box 6.3 *Competing causes of disease and death*

In the developed countries, the epidemiological transition has come to a stage that chronic diseases - particularly from old age - have become predominant. These diseases are characterized by (*older*) *age* and *endogenous* causes (either inborn or acquired) and behavioural influences. Even if patients can be cured, they remain in a risk situation: age increases further and competition from and replacement by other causes of disease and death (mainly of endogenous nature) are excessive. Competition and replacement also plays a very important role among the 'under-fives' in the developing countries, especially those in the early stage of the health transition. Here, the presence of *exogenous*, environmental causes of disease and death for that *young age* group are so widespread that isolated (medical) action against only one or a few causes does not result in a significant health improvement or rise in life expectancy. On the contrary, the steady and continuing health improvements that do occur demonstrate that there are coinciding positive influences over a broad range (see too Box 6.2), like improvements in family income and the educational level of mothers, sanitation, schools, nutritional patterns and medical efforts. (McKeown, 1976; WHO, 1993, World Bank, 1993, UN, 1994).

5 An example of the influence of education was seen towards the end of World War II where, in the west of the Netherlands, food and clean water were in insufficient supply. The well-educated population was instructed how to extract the maximum nutrition from the available food. By filtering and then exposing the water to the sun's ultraviolet light the micro-organisms count was drastically reduced.

6 The occurrence of many diseases can be both positively and negatively influenced, especially at the population level, by behavioural conditions, which are often closely connected with the economic situation. Examples are heart attacks (diet, lack of exercise), cancer (smoking, smoked food products), fecal-oral infections (lack of hygiene).

agricultural techniques are available to meet the needs of larger populations. But there will be local and regional exceptions to this positive trend, resulting in a lack of access to food caused by climatic disturbances, poor socioeconomic conditions and inequity (Boxes 6.5 and 6.6).

Total water demand is also assumed to be met by total supply in the scenario, but - as outlined in Chapter 4 - the risks here are larger, not in the least because it is more difficult and expensive to trade water than agricultural products from surplus to deficit regions. Currently, despite the successes of the Water Decade (the eighties), the yearly increase in the number of people with access to *safe* water remains about equal to the annual growth in population (WHO, 1993; World Bank, 1993). For the more distant future more problems are expected. Even if the problems of water quality are ignored, possibilities for increasing the quantity of freshwater supplies are limited and shortages can occur in many regions at any time.

The assumptions in the scenarios used in the *TARGETS* models with respect to nutrition and water demand could have a positive effect on health, but depend on adequate investments in the agricultural and water sectors to increase productivity and make the resources available to all segments of society.

The net health effects of *environmental factors in a narrower sense (e.g. chemical pollution*) are lower than those related to the broader environmental health determinants in absolute figures. Nevertheless, this should not mask the fact that local absolute disease and death figures resulting from these environment-related factors can be - and indeed have been - substantial. For example, the London Smog of the fifties, the Minimata (mercury) disease in Japan, the Bhopal calamity, and the congenital deformations in the vicinity of Chernobyl after the 1986 accident, are examples of serious local effects of chemical pollution. These kinds of exposure can, however, in the near future, be either prevented or limited, but only if appropriate safety measures are taken. A longer effect in time and space is to be expected from large changes, like the altered water supply to Lake Aral that affects an increasing number of people (WRI, 1994; Donkers, 1994).

6.3 The health status of the world's populations

Past and present

Major improvements in health have been achieved over recent decades in terms of decreases in overall disease and death levels, and even in terms of more specific parameters such as the incidence of infectious diseases or prenatal and infant deaths (WHO, 1993, World Bank, 1993; see also Figures 6.2 and 6.3 - the elements of latter figure are discussed in the next section). Life expectancy for most populations has greatly increased, leading to sharp increases in population despite declining birth rates in many countries (UN, 1994; Figure 6.2c). However, in some countries the fertility transition is slow or stagnating. Up to 2015, the increase in health levels and life expectancy may be hampered at local levels by lack of development in infrastructure and, in the environmental fields, shortages of food and water. However, for the world on average, the health enhancing factors discussed in section 2.6.2 are likely to prevail.

Figure 6.2 shows that communicable diseases have a major impact, accounting for 41 per cent of all deaths in developing countries, compared to only 5 per cent in the formerly socialist economies of Europe (FSE) and established market economies (EME). Non-communicable diseases, excluding injuries, account for 50 per cent of all deaths in developing countries, but as much as 87 per cent in the FSE/EME.

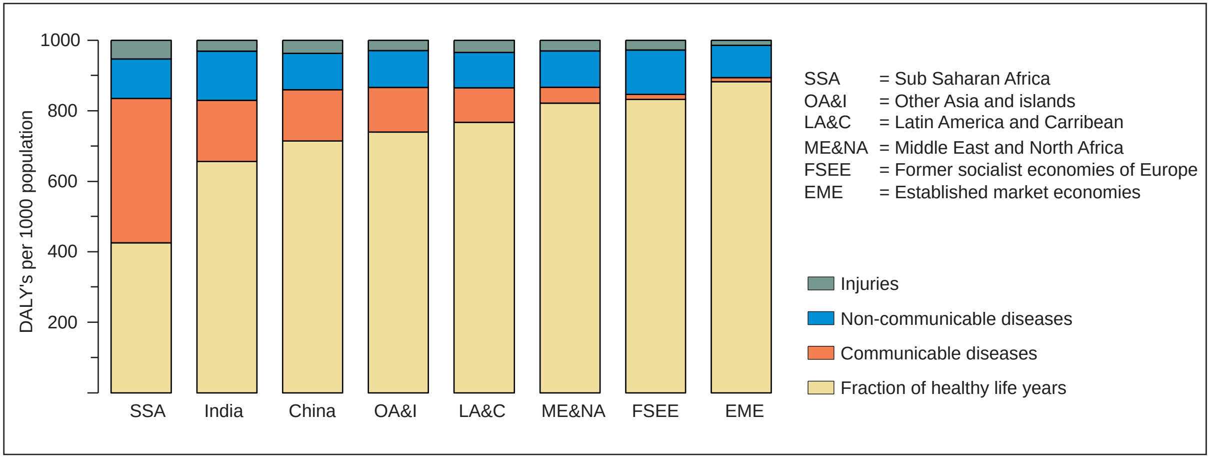

Figure 6.2. *Disability Adjusted Life Years (DALYs) lost, 1990*
Source: World Bank (1993).

During the last century, disease and death rates for particularly infections were higher in the newly developed countries than they are at present in developing countries. With respect to the transition concept, many developing countries are on their way from the generally poor health universal a century ago to a much better health status. Figures 6.2 and 6.3 resemble each other in that the socioeconomic, demographic and health transitions over time in the three model case studies can also be distinguished in the eight regions that at present are in different stages of transition, as in the World Bank publication about health developments. Especially infant deaths from communicable diseases in developing countries are declining. This will lead to significantly decreased global death rates, as outlined in Figure 6.4, which shows the cause of death by age and region for the 50 million deaths registered annually. The gains in DALYs (largely caused by reduced deaths in FSE and EME) can be clearly seen. This progress is also likely to occur in developing countries.

At the moment, children 0-4 years of age ('under-fives') account for more than 25 per cent of global deaths. These occur almost exclusively in developing countries, where 85 per cent of infant deaths (10.6 million) is caused by communicable diseases (nearly half of these are diarrhoeal diseases). A child in a developing country has 12 times the chance of dying from a communicable disease before he/she is five than a child in developed countries (Figure 6.5).

The future

In the Conventional Development scenario it is assumed that the demographic and health transitions described for industrialized countries will also occur in other countries in interaction with socioeconomic developments (see also Chapter 2). In the previous sections, the CD medium-population growth scenario was taken as the basis for the assessment of changes in the global cycles, in land use and in biodiversity. This section, however, will tentatively explore to what extent changing health determinants - including the environmental factors - have an impact on health and demography itself.

Since adequate health data for all six regions distinguished in the rest of this chapter are not available at this stage, three countries representing three different stages of the health transition have been selected to illustrate the characteristics of regions that are found in the different stages of these transitions. The three countries are India, Mexico and the Netherlands, representing the late first, second and third stages of transition, respectively. These countries have been studied using a

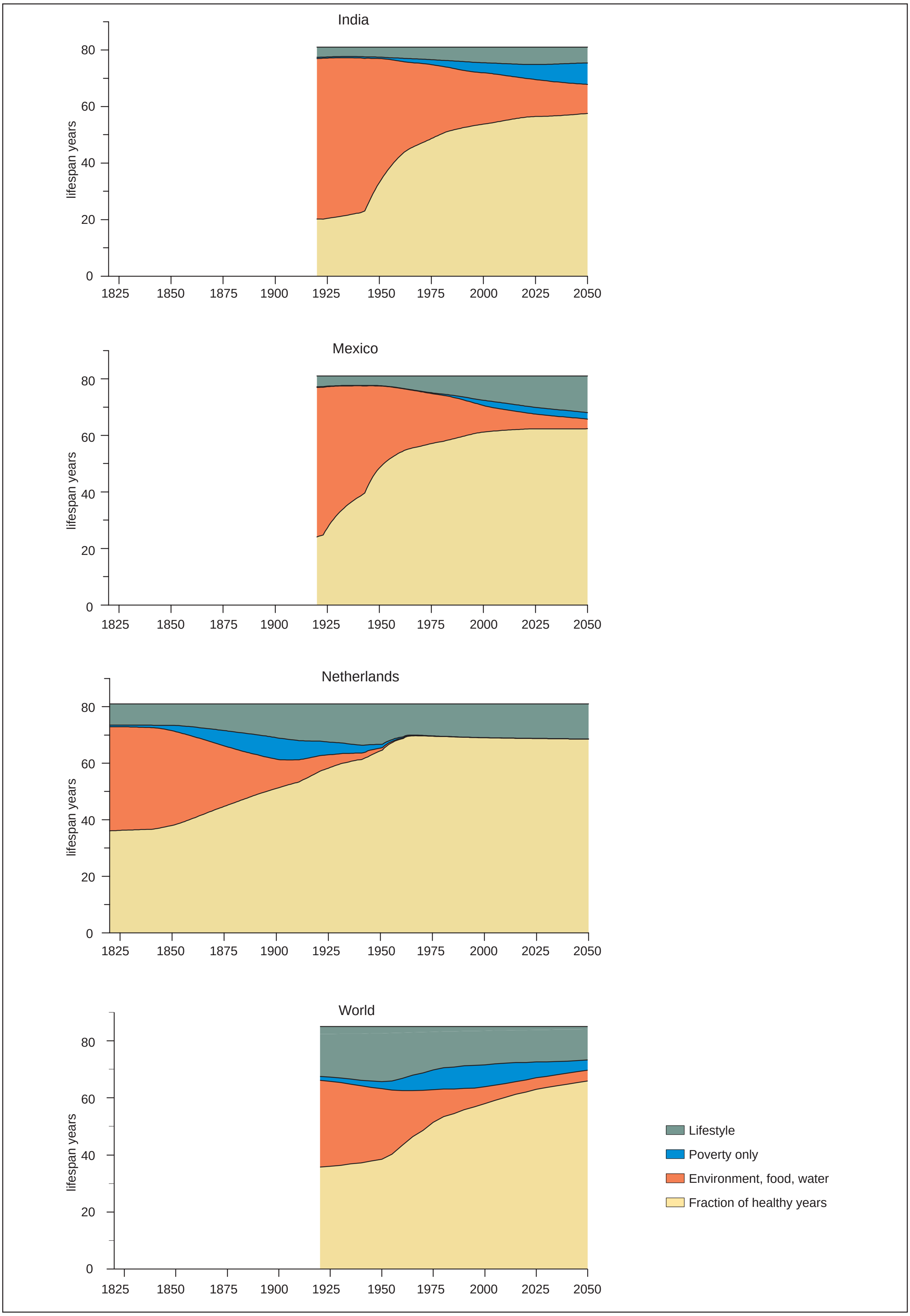

Figure 6.3. *Past and projected disability Adjusted Life Expectancy Years (DALEs)*

Note: Preliminary outcome of the TARGETS population and health model, version 1.0. (See also note 8).

Source: Niessen and Hilderink, (1996).

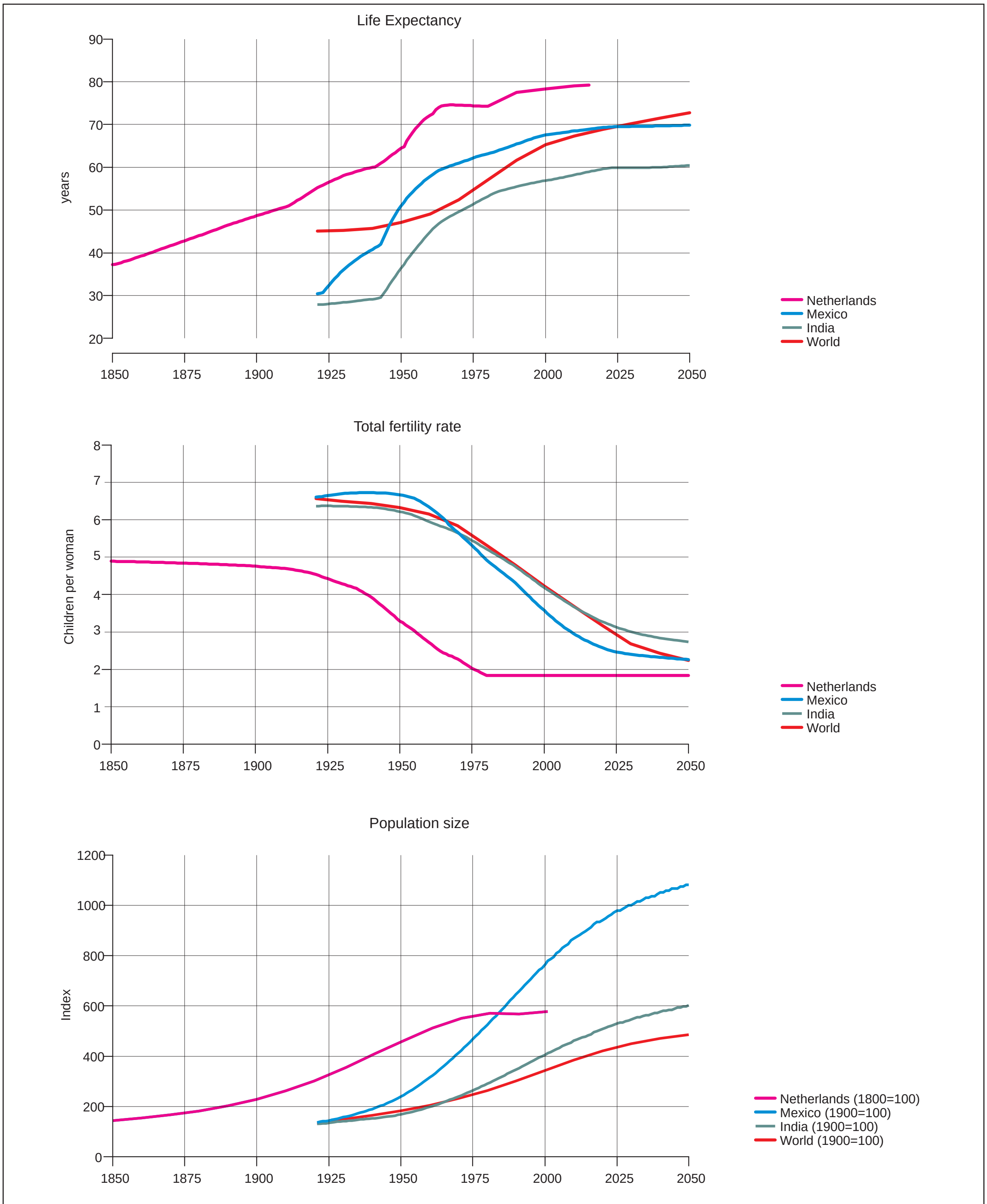

Figure 6.4. *Past and projected population change*
Source: Niessen and Hilderink (1996), Statistics Netherlands.

preliminary version of the health and population submodel of the TARGETS model[7]. The main driving forces for the various demographic stages are fertility and life expectancy (Figures 6.3a and b).

[7] It should be noted that the calculations presented here are based on a very preliminary version of the model, primarily to illustrate how different countries could go through the different stages of demographic and health transitions. From the results it should not be concluded that the values of the selected indicators will or should indeed be achieved.

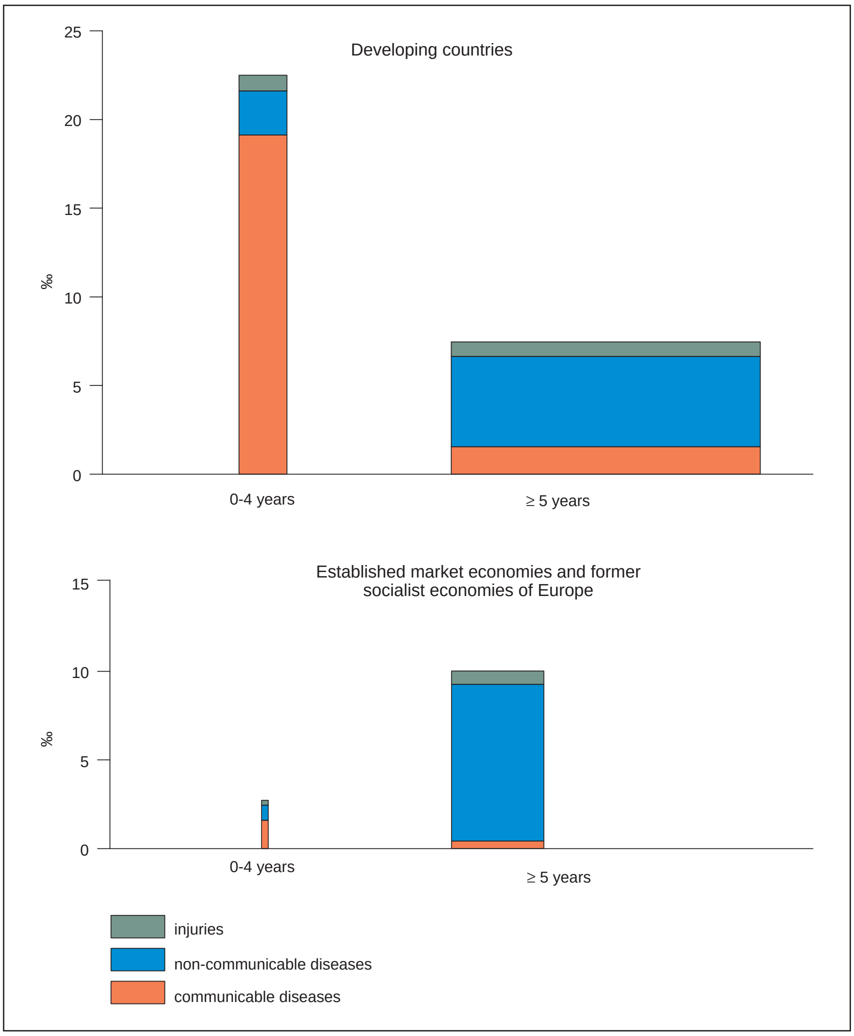

Figure 6.5. *Death by cause in 1990*

Note: The width of the bars is proportional to the size of the population involved.

Source: World Bank (1993).

Different from traditional demographic projections, these factors in TARGETS are not exogenous, but derived from a set of health and fertility determinants[8]. Fertility rates are found to

[8] The TARGETS model outcomes for DALEs in three countries. The input parameters or health determinants in the model are as follows (with threshold values; see appendix III on the TARGETS modelling framework):

Scenarios
- Gross National Product (GNP). Absolute increase (%); annual growth percentage (US $ p.c.).
- Total health service expenditure. Absolute increase (3.7-8.2 %) (percentage of GNP).

Environment, food, water (see Figure 6.32)
- Malnourished (percentage of population per age class with less than basal metabolic rate) (< 1575 kcal/day)
- Malaria exposure (the presence of malaria-infested mosquitoes)
- No access to safe water (access to safe drinking water more than 200 m away)

Poverty only (see Figure 6.3)
- Absolute poverty line (percentage of total population < 340 US $ p.c. annually).

Lifestyle (see Figure 6.3)
- High (socioeconomic status (SES) only (literate, high income, or both; > 680 US $ p.c. annually)
- Tobacco abuse (> 15 cigarettes/ day)
- Hypertension (diastolic pressure > 90 mm Hg; systolic pressure > 180 mm Hg)

converge towards the levels of the industrialized countries within the same time-scale in the two selected developing regions and in the world as a whole, confirming other projections (UN, 1994). Life expectancy converges to a global average of around 70 years by 2050, which is, however, less than the present 75 years or more in developed countries. This discrepancy is due mainly to the remaining large differences in income levels.

As to absolute numbers, the increase in the world population to about 10 billion in the course of the next century has been derived from the TARGETS model using the input assumptions with respect to health determinants. Although the preliminary nature of the calculations makes definite conclusions somewhat premature, a sensitivity analysis with TARGETS suggests that the improvements in health determinants achievable with the assumed income levels and other socioeconomic conditions such as education, may well lead to lower population growth than that derived from many medium-term projections, including the Conventional Development scenario.

Evidently the slower population growth projected depends very much on a mixture of optimistic tentative assumptions on investing part of the increasing wealth in health, environment (including food and water) and social services. It should also be stressed that the model outcomes might have been different if another selection of health determinants had been used - even taking into account that the current model version has been tested against historical data. In fact, if investments in health and social development are lower than assumed, negative developments for health determinants and other factors influencing demographic trends may occur and more rapid population growth may thus ensue.

This underlines the dependence of the findings on exogenous assumptions about demographic and economic growth named in the previous sections. On the one hand, lower economic growth may lead to more rapid population growth and more poverty-related environmental degradation of local land and water resources. On the other, faster economic growth may lead to slower population growth, but to a greater consumption-related disturbance of the global and regional environment, including - but not limited to - climate change and acidification.

Effects of human health

Since larger and healthier - and thus, on average, older - populations will place additional demands on the economy, especially if a *distant time horizon* is taken, the first of the three questions with which this section opened, could be reversed to form a new question: what is the influence of human health on the environment ?

As outlined in the previous sections, increased economic activity, more water extraction, a growing demand for food, both in quantity and quality, and higher levels of energy consumption, will all impose pressures on the environment (UN, 1992). In Chapter 3 the disturbance of linked global cycles was discussed. Chapter 4 established the feasibility of global food and water security, but also the conditions under which this could be achieved and the associated large uncertainties and vulnerabilities. Chapter 5 made clear that under ‘Conventional Development’ assumptions, losses of global biodiversity appear unavoidable, including the potential loss of valuable wild varieties of the world’s staple foods.

All these risks imply that, especially *in the longer term*, environmental degradation could significantly affect human health.

6.4 Are goals considered potentially achievable?

The World Health Organization, the United Nations and the World Bank have set priorities for health programmes and formulated aims for the year 2000 (WHO, 1993; World Bank, 1993). Relatively less money should be spent on clinical care and more on prevention. In particular, education in hygiene, safe water and other facilities, like waste control and sanitation, should be supplied to control or limit the spread of waterborne diseases (Box 6.4). Vaccination and prevention programmes eradicated smallpox in the seventies and will presumably eradicate poliomyelitis and dracunculiasis and limit hepatitis A by the year 2000; in the Americas poliomyelitis has already been wiped out. Above mentioned organizations are calling for special attention to be given to the health problems of children and women, and primary health care in rural areas and in the rapidly expanding urban areas (Box 6.6). Emphasis is also placed on pollution control, which is of growing importance according to health authorities.

‘What can be done to improve health and how effective are environment-oriented responses designed to achieve this?’, was the third question this chapter sets out to address. The model calculations in this section suggest that not before long most of the above goals with respect to demography and health may be achieved for most populations in a Conventional Development world. However, many of the developing countries will continue to stay below the average due to unequal levels of development. Environment-related health determinants are likely to decrease in importance over the next few decades, again, with regional exceptions (Box 6.5).

Box 6.4 *Diseases: declines and increases*

The Figures 6.2, 6.3 and 6.5 show how much death from *communicable diseases* has decreased in developed countries. During the nineteenth century death rates due to these diseases were higher than those of the developing countries now. This implies that already much has been won in developing countries and still more is to be gained: e.g., the abatement of infectious diseases has been effective in the last few decades, especially among children 0-4 years old.

Particularly the decrease in disease and death levels from *waterborne diseases* has been impressive. Health engineering, oral re-hydration, education and behavioural change were key elements in this change for the better. An exception is cholera, which reached epidemic levels in South America in the beginning of the nineties and is found at present in South East Asia; case fatality rates are comparatively low, however, and vaccine developments are promising. Among the *arthropod-borne diseases* malaria poses serious problems: resistance of the parasite *Plasmodium* against drugs and of the mosquito *Anopheles* against insecticides is increasing. About 300 million people are infected, 100 million suffer from clinically manifest malaria and the annual number of deaths amounts to over 2 million. Malaria and the mainly *respiratory disease*, tuberculosis, account together for 10 per cent of the registered deaths per year. Tuberculosis causes a total of 3 million deaths annually, making it the leading single cause of death in the world (incidence over 9 million), and (multi-)resistance is a growing threat to future treatment. There is still no effective vaccination for either disease.

Particularly in Africa (see Box 6.5), tuberculosis is second to the AIDS epidemic in number of deaths, being responsible for at least 30 per cent of the cases. The mainly *sexually transmitted* HIV infections are on the increase in most countries, leading to approximately 20 million sero-positive people in 2000. An incidence of several millions annually will, because of the incubation period of years, lead to a similar incidence of AIDS and a comparable death rate later. Treatment of HIV infections also meets with the problem of resistance; a vaccine is still far away. The problems mentioned are not equally distributed over developed and developing countries. Some developing countries bear comparatively large burdens when it comes to these diseases; very often lack of funds and infrastructure resist efforts to solve the problems (see also Box 6.5). Here is an important challenge for international cooperation. Despite the setbacks indicated, this can lead to further health improvements. By concerted actions smallpox has been wiped out, and in the Americas polio has been annihilated. Dracunculiasis is likely to be overcome in this decade and hepatitis A will decrease sharply through the current expanding vaccination programs. (Cairncross, 1983; WHO, 1993; World Bank, 1993; Van der Velden, 1995).

Box 6.5 *Entrapped populations in Africa*

A group of African countries around the equator are suffering from a cluster of interrelated factors deriving from and resulting in weak economies, destabilization, poverty and ill health. In world maps these countries show almost invariably the highest rates of perinatal, infant or maternal deaths, and the highest rates of occurrence of the diseases mentioned in Box 6.4, like AIDS, tuberculosis and malaria. GNP, family incomes, educational levels, health expenditures and life expectancies are among the lowest in the world. In some of these countries there are signs of a failing demographic transition; it is feared that they are entering what Maurice King has called the 'demographic trap', a situation of population expansion that absorbs all economic growth, if any growth occurs at all (World Bank, 1993; UN, 1994; Van der Velden, 1995).

Further in time (2050 and beyond), the situation might change due to the time lag in the influence of many negative factors, as discussed in the previous sections. In the scenario adopted, increasing demands for water and food are assumed to be met. According to the calculations, the projected socioeconomic developments and the associated environmental changes will, on average, not have significant negative effects on human health at the global and average regional levels. However, there are three important caveats to this finding.

First, because of local differences in resource and income endowments, the availability of food and water may continue to be limited at the subregional level, with ensuing serious consequences for human health.

Box 6.6 *Urbanization: growing population, growing pollution*

Population

The ongoing urbanization process is likely to result in more than half of the world population living in cities by the year 2015. A growing part of the expanding city populations will be living in quarters and areas unfavourable to health. Many of the negative health determinants discussed in section 6.2 coincide here: unemployment, underemployment, low income, lack of education, malnutrition, health impairing life style and poor social environments and housing. The urban poor generally not only have to live with these risk factors, but they also often live on polluted sites or near waste dumps and industries, and are exposed to natural disasters such as landslides and floods. Overcrowding and absent or deficient sanitation, piped water and garbage disposal contribute to ill health. Disease and deaths among children are high among the poor in large cities, with a large contribution from communicable diseases. The contributions from respiratory conditions in disease and death figures of all age classes are showing a growth tendency, fine particle air pollution being a major cause.

Air pollution

The population in urban areas, particularly in large cities and so called mega-cities and their surroundings, is suffering health impairment by air pollution at an increasing rate. Apart from smog caused by combustion processes in industries, houses and cars, fine dust particles from roads, and building and demolition sites, have an increasing negative influence on the respiratory functions and diminish the quality of life and even the life expectancy. Many studies are done in the 20 mega-cities numbering 5 million people or more. We will present some results from studies in Bombay, India. Greater Bombay, located on several islands with a total surface of only 600 km^2, numbered nearly 10 million people in 1991. Bombay has approximately 40,000 small and large industries and a vastly expanding motor traffic system. Measurements in 1992 indicated that the total suspended particles exceeded the WHO air quality guideline more than twice for about 800,000 people, including 300,000 car drivers. Particle air pollution in Bombay is claimed to have caused 2800 deaths and 4000 hospital admissions in 1992. (WHO, 1992; WHO, 1993; Cartledge, 1994; UN, 1994; Deelstra, 1996; WHO, 1997; Dockery and Pope, 1994).

Box 6.7 *A health problem in rural areas: acute agricultural intoxications and long-term health risks*

Agricultural poisoning is a largely under-rated danger to health and life. Yearly at least 1 million cases of poisoning by pesticides occur and at least 15,000 deaths are registered. This is an underestimation, since in the United States alone about 300,000 cases of pesticide poisoning are known to occur annually (among 4-5 million exposed workers; incidence 6-8 %). Many agricultural agents are considered or proven to be carcinogenic or teratogenic. Exaggerated use of herbicides and of pesticides such as DDT in the vineyards, are regarded to be the cause of high incidences of bone disease in the newborn in Azerbaijan.

Moreover, the agents are posing an increasing risk for the quality of drinking water. Especially in areas where cultures require high doses of chemical agents, e.g. Dutch tulip fields, crops at the end of the eighties were treated with 100-200 kg of chemicals per 10,000 m^2 yearly. Since then, reductions to well under 50 kg have been achieved (WHO, 1993; Cartledge, 1994; Van der Linden, pers. comm.). Notwithstanding the many victims of local pesticide use, especially in developing regions, preliminary model calculations indicate that there is no need to fear that human health will suffer from a process of toxification at the level of world regions in the long term if adequate policies are implemented (Verbruggen *et al*., 1996, in prep.). An environmental transition in the application of pesticides can be witnessed in the developed regions; this consists of a shift from highly toxic and persistent chemicals to more degradable alternatives, and a more selective and efficient use. If the growth in the worldwide use of pesticides is accompanied by policies to enhance this transition, toxification at the regional scale can be avoided and the risks of acute intoxications may be reduced.

Second, the finding from the scenario is conditional: the assumed economic growth will have to be achieved and accompanied by investments in social and environmental development similar to those that have taken place in industrialized countries.

Third, it should be noted that the impact of a number of environmental changes on health were not (and could not) be taken into account at this stage of analysis. These include land degradation, the destruction of the cradle areas of the world’s staple foods, climate change and acidification, and the hazards of persistent organic pollutants (Box 6.7).

At present and into the near future (2015), the health gains from approaches that may have a negative effect on the environment, such as the use of herbicides and insecticides, outweigh the possible disadvantages for health caused by damaged ecosystems. Now and in the near future a comparatively small percentage of DALYs lost can be attributed to direct environment-related factors such as chemical pollution. These losses are dwarfed by the enormous increase in life expectancy occurring virtually everywhere in the world[9].

The answer to the third question then, of how effective environment-oriented interventions are, depends on the scale of the problems and the . At the local level, the existing problems may already be considerable; however, the solutions are only found on larger scales. Ensuring that local problems do not develop into larger regional ones seems to be the most effective approach. Taking into account the time scale, this means that investment in the preservation of natural values will *now* lead to both better health conditions and lower levels of investment in repairing damaged ecosystems *in the future*.

[9] For example, the use of DDT continues in many regions despite its negative influence on many organisms and biodiversity (see also Box 6.4). In areas where it has been introduced there has been an obvious increase in crop yields, wealth and nutritional status. Combined with more effective medical interventions, the health of the population has improved, resulting in a longer average life span.

6.5 Possible responses

For a lot of populations, human health has improved or is improving, but many regional environmental threats remain. The consequent improvements in life expectancy are, despite decreasing fertility, the driving force behind the expansion of the world population. In the context of this chapter, two issues emerge.

(i) The future size of the population is very much determined by the inertia within the population dynamics as it now exists. Therefore, at least as far as the near future is concerned, half the increase in the size of the population is determined by the number of (female) children living today (Bulatao, 1992). This will be even more true if fertility rates further decline. Hence, for a reduction in environmental pressures in the near future, it will be effective to focus on consumption and production patterns. Nevertheless, population policies implemented in the short term do have an important effect on the size of the population in the more distant future. Notably, calculations using the model suggest that the level at which the populations of the world may eventually stabilize could be significantly lower (when maximum investments are made in optimizing determinants of fertility and health) or higher (when low investments are made in optimizing determinants of fertility and health) than current medium estimates. Declines in fertility and death could be enhanced by education and facilitating the use of contraceptive methods. In general, the strategies for further promoting fertility decline and health are outlined in detail elsewhere (e.g. UNFPA, 1996; World Bank, 1993; WHO, 1993; UN, 1994).

(ii) The second issue emerging from the general analyses is that especially environmental degradation is a factor that can currently determine human health at the regional and local levels. In future, the scale and effects of this process may change as indicated in the other sections of this chapter. We conclude that if the population and income growth projected in the adopted scenario is not matched by investment in the social development and environmental protection worlds, environmental degradation may pose a serious threat to regional human health - either directly through environmental factors, or indirectly, by reducing the availability of food and water of sufficient quality and quantity. Moreover, global environmental changes might increase the expanse of the areas of disease vectors like malaria and dengue (Martens *et al.*, 1995). Environmental preservation and future human health is one of the important reasons to invest in a sustainable and sustaining environment. The next section turns to possible responses to enhance environmentally sustainable development.

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7 RESPONSES: PRIORITIES AND STRATEGIES FOR MAKING PROGRESS IN IMPLEMENTING AGENDA 21

7.1 Taking stock: assessing previous findings

This report provides a model-based quantitative assessment of what the future of the global environment may look like if present trends in demography, social and economic development and policies (as outlined in the Conventional Development scenario) continue.

Figure 7.1 shows the main trends in the development of environmental pressures, the state of the global environment and resulting impacts following from the assumptions of the Conventional Development scenario. The most prominent features are the loss of natural area as a result of the expansion of agricultural land, the increase in area affected by a scarcity of water (leading to a substantial increase in the number of people facing water problems) and the large area affected by climate change as a result of the uncontrolled increase in atmospheric carbon dioxide concentrations.

In summary, it appears from the assessment that conventional development may well lead to a future with the following characteristics: (1) a doubled population that *on average* is wealthier and in better health, but (2) lives in a world with scarcer and more degraded natural resources (like land and water) with much less biodiversity, increasing emissions of pollutants, a climate that has changed and is still changing, and (3) a remaining large per capita income gap between regions that - at least for the next few decades - will even increase in relative terms.

As indicated in Table 7.1, the Conventional Development scenario projects a number of economic, social and environmental achievements. However, these are at risk if the assumed underlying social and economic developments are not realized, while a range of environmental and social problems is likely to persist in any case. Consequently, many goals of Agenda 21 will not be met in a Conventional Development world and more or different efforts will be needed to enhance sustainable development.

Table 7.1. *The Conventional Development scenario: achievements, threats and remaining problems*

	Achievements	Threats to achievements	Remaining problems
Economic	+ higher incomes + higher efficiency	less / uneven economic growth	- remaining poverty - resource depletion - increasing income inequalities
Social	+ better health + longer life + higher literacy + slowing of population growth	insufficient social investments & employment	- social inequality - remaining poverty related health and social problems
Environmental	+ lower resource intensity + better sanitation & water supply + control of local pollution	insufficient environmental investments	- loss of biodiversity - degradation of water & land resources - disturbance of cycles

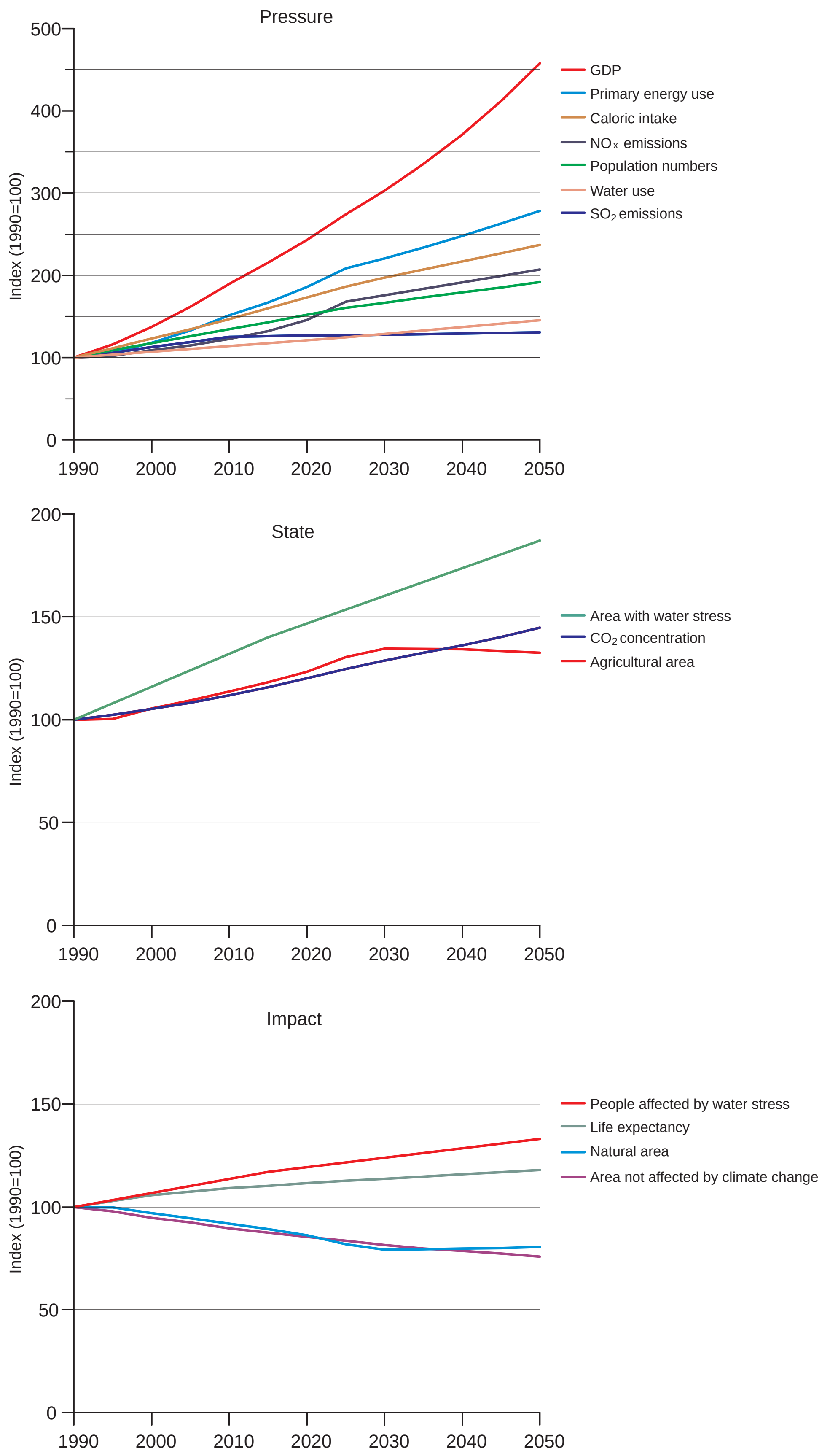

Figure 7.1. *Projections of pressure, state and impact indicators for the Conventional Development scenario*
Source: RIVM, this report; Raskin *et al*. (1995); Posch *et al*.,1996.

Discussion of the results

Of course, the above findings very much depend on the scenario assumptions used. If more optimistic assumptions had been made with regard to technological progress and autonomous responses to environmental degradation, the environmental impacts would be less severe. Likewise, many of the assumptions of the Conventional Development scenario - such as the practical availability of energy resources, or the potential for raising agricultural yields or expansion of agricultural land - can be viewed as being too optimistic (Raskin and Margolis, 1995; Brown, 1996). Given the fundamental unpredictability of the future, it would have been better to work with a set of different baseline scenarios; this will be proposed for future editions of the GEO.

Leaving aside the issue of the scenario assumptions, the assessment of the future state of the global environment presented above has many limitations; for this reason the results need to be viewed with due care. The uncertainty of the results stems from various factors: the limited scope of the assessment, the partial integration, the still relatively highly aggregated analysis, the sensitivity of results to model characteristics and scientific uncertainties.

For reasons of availability of certain modelling tools and global data, the assessment has been restricted to only a limited number of environmental issues, notably climate change, acidification, land and water availability, biodiversity and human health. As a consequence, the assessment leaves out issues like the depletion of minerals, non-terrestrial stocks (e.g. fish), and more local environmental problems with respect to waste, (urban) air pollution, toxification, poor drinking-water quality and so on. The picture, therefore, is far from complete. Even given the limited scope, it was not possible to perform a fully integrated analysis. The assessment of future freshwater availability has not yet been linked to climate change to account for a possible change in water supply. Likewise, the modelling tools available do not yet enable a quantitative feedback of the results from the assessment of the food and freshwater availability to the assessment of the future state of health. Finally, assumptions on population used in the environmental assessment were exogenously defined by the scenario instead of been calculated by the health model.

Integration is also limited by the scale of analysis. Regional and global aggregation masks significant variations in the value of both socioeconomic and environmental variables used, while unavoidably, leaving out many others of great relevance to local environmental and social conditions. One example is income distribution within regions. At present, levels of inequality in income are increasing worldwide (UNDP, 1996). It can be argued that if present levels of inequalities in income are maintained at the current levels (which is not an unreasonable assumption for a Conventional Development scenario) it can be expected that even when average incomes rise, locally poverty-related environmental problems, like overexploitation of local natural resources and environment-related morbidity and mortality will remain or could even be further aggravated, given trends in population growth and urbanization.

From these limitations it should not be concluded that the results do not make any sense or that the projected future is likely to be too pessimistic. Just because of the many limitations it can certainly be argued that the projections are likely to give a too optimistic picture of a conventional development future. Clearly, more analyses are needed to enhance the understanding of the sensitivity of the results to scenario and model assumptions and levels of uncertainty.

Notwithstanding these limitations, the ‘what-if’ assessment demonstrated in this report offers useful insights to support the overall aim, namely, to identify policy priorities and effective strategies for sustainable development for progress in implementing Agenda 21. This chapter will therefore continue with a brief discussion of the kind of transitions needed in human interaction with the environment to arrive at more sustainable forms of development. These will then be used to make a preliminary assessment at the regional level of priority challenges for policy as they appear in the scenario analysis in the preceeding chapters. The focus of the remaining part of this section will be on potential policy strategies that could enhance the effectiveness in pursuing the necessary transitions. Finally, some preliminary assessment of the costs of policies promoting sustainable development will be made.

7.2 Transitions to more sustainable forms of development

The framework for the analysis in this chapter was presented in Chapter 1. The focus is on the dynamic interactions between the human and environmental systems. From this systems-analysis perspective, one important aspect of environmentally unsustainable development can be defined as the rapid expansion of the human population and its economic activities within a physically and ecologically limited space. Although the limits of the 'carrying capacities of natural systems' or 'ecological space' are to a large extent politically subjective, scientifically uncertain and not static (see Box 7.1), it can be argued that uncontrolled increase in the pressures produced by the human system will eventually exceed the limits of natural systems. These systems will first degrade and ultimately collapse, with negative impacts on the human system due to their inability to provide sufficient food, water, raw materials, energy, medicine, and the conditions for safe and healthy settlement and recreation.

The overall challenge of sustainable development from a systems-analysis point a view, therefore, is to avert global and/or regional crises, in which environmental degradation hampers or even retards human development[1]. To prevent such environmental crises taking place, the human pressure on the natural environment needs to be limited to sustainable levels, balancing socioeconomic development with the preservation of natural resources.

The human pressure on natural systems is a function of population size, the level of production/consumption per capita and the kind of technologies used (Ehrlich and Holdren, 1971; Commonor *et al*., 1971). The extent to which humans can exploit the functions of natural systems in a sustainable way within a changing 'environmental utilisation space' is not fixed. From an environmental perspective, sustainable development can thus be perceived as the pursuance of a series of different, interacting transitions, which preserve, enlarge and improve the use of the global and regional 'environmental utilization space'. The following environmental transitions are distinguished here[2]:

- <u>a land/food transition</u>: a shift to intensive but sustainable food production systems, reducing or reversing land degradation, while preserving ecological resources (water, biodiversity, valuable natural zones which are currently threatened by encroachment) for use by future generations;
- <u>a water transition</u>: a shift towards integrated water management, balancing societal and

[1] For such an analysis see, for example, Meadows *et al.* (1991*): Beyond the limits. Confronting global collapse; envisioning a sustainable future*. Although its findings may be debatable in some respects, it provides a clear illustration of the argument presented here.

[2] The concept of environment-related transitions has been discussed by Rotmans (1995) and by Raskin *et al*. (1995). Rotmans distinguishes between an environmental transition composed of a water, land and biogeochemical transition, and a human transition, combining health and energy.

Box 7.1 *Ecological limits and the exchangeability between different types of 'capital'*

With respect to the limitations of natural systems concepts like 'carrying capacity' (Ehrlich and Holdren, 1971, Commonor *et al*., 1971) or 'environmental utilization space' (Opschoor, 1992; Opschoor and Weterings, 1994) have been used. The concept of 'carrying capacity' has been criticized as being too static and value-loaded: technology can make nature more productive (e.g. in agriculture), make available additional resources or substitute existing ones (e.g. raw materials, energy, human resources) and improve the efficiency of resource use. Moreover, it is argued that it is impossible to determine sustainable limits objectively (e.g. the number of species that need to be preserved for ecosystem stability). It has been noted that the number of people the earth system can support depends on human choices, e.g. desired consumption patterns (Cohen, 1995). The concept of 'environmental utilization space' (EUS) does take some of this criticism into account, as it includes the idea that the total support which natural systems can provide to society is both a function of their quality and of the technologies applied. This makes it a dynamic concept. It is also acknowledged that the EUS cannot be based on scientific information alone, but implies normative positions vis-à-vis uncertainties and risks (for an overview, see Milieu, 1994)

Related to this is the debate between advocates of 'weak' and 'strong' sustainability (e.g. Pearce, 1993). Weak sustainability assumes that natural resources (or 'capital') can in principle be substituted by human-made economic capital, and human (including social) resources. For development to be sustainable present generations should leave to future generations a total stock of natural, economic and human capital that is at least as large as they have inherited, however, its composition may change (World Bank, 1995a). This vision is particularly popular among mainstream economists. The proponents of strong sustainability believe that natural resources cannot be substituted by human-made capital and that the two should be viewed as fundamentally complementary. They argue that, apart from the intrinsic value, human welfare will always depend on the proper functioning of natural systems. This approach is shared by many ecologists and ecological economists (e.g. Daly, 1995). In a middle position could be 'sensible' sustainability that would take into account the critical levels below which no type of capital must decrease. 'Since we do not know exactly where the boundaries of these critical limits for each type of capital lie, it behooves the sensible person to err on the side of caution in depleting resources at too fast a rate' (Serageldin, 1996).

The approach in this report comes closest to the third view. Due to scientific uncertainties and normative aspects, neither the number of people the earth system can support nor the precise ecological limits can be determined objectively and, in fact, may be related to different (cultural) perspectives (Van Asselt and Rotmans, 1995). However, it is believed that there are certain thresholds beyond which environment-related risks to human well-being and development, as well as the costs of ameliorating changes or adapting to them in (the variability of) natural conditions, will or at least may increase rapidly. Technologies can of course play a positive role in avoiding exceeding these thresholds, but only to the extent that they are widely available and accessible, and broadly applied. Moreover, if current trends in socioeconomic driving forces continue, technology can postpone but not avert these dangers. Ultimately, the uncertainties about environmental limits will have to be balanced against the risks of counting on the timely availability of new technologies to extend ecological limits and on the ability of (future) societies to adapt to changing environmental conditions.

ecological demands and safeguarding long-term sustainable supplies, e.g. by minimizing the depletion of fossil groundwater resources, and using water more efficiently;

- an energy transition: a shift towards greater efficiency in the conversion, use and production of energy as well as from the use of fossil fuels to renewable resources;

- a material transition: reducing the intensity of the use of materials[3] in production and consumption, including a reduction in the production of waste and emissions of pollutants[4] by changing production technologies, closing material cycles (recycling) or substituting less harmful (renewable) substances or processes.

There is some evidence that some of these environmental transitions (e.g. the material transition) are beginning to take place in certain parts of the world (World Bank, 1992; 1995a). They should not, however, be viewed as autonomous developments. Like the demographic and economic transitions in the past, they are linked to and influenced by socioeconomic conditions and institutional developments. These developments have not been included in the model-based assessment described in this chapter. However, as they are intrinsic to the strategies needed to support the above-mentioned environmental transitions they require attention here.

Social and economic conditions

Alleviating poverty and inequity
Although no simple relationships between poverty and environmental degradation, and welfare and decreasing fertility rates, have been established (e.g. World Bank, 1995b), it is widely understood that generally speaking poverty and social inequality hamper the sustainable use of natural resources and the reduction of fertility rates (UNEP, 1995; Reidhead *et al.*, 1996). Poverty reduces the options people have to take into account longer term considerations, exert effective pressure on polluters (World Bank, 1996) and to invest in more productive and sustainable agricultural production methods. Often, rural poverty is directly linked to a lack of access to suitable agricultural land, e.g. as a result of an unequal distribution of land. A more equal distribution of land, such as through land reforms, has often been an important condition for effective investment in rural productivity and more sustainable use of natural resources in the past and will probably continue to have this effect in the future. There is also great deal of evidence that the economic dependency of older generations on younger ones, low levels of education and (formal) employment of women (resulting in early marriages) and limited knowledge and access to means of birth control, have a negative impact on the reduction of fertility rates. This delays the demographic transition. All these factors relate to poverty and social inequality (see Chapter 6). Therefore, social policies that provide the poor (especially women) with access to social services (like primary health care, education), that strengthen the social and economic position of women in society, and also offer the elderly some kind of social security, are important factors in enhancing the demographic transition (UN, 1994).

Changing consumption patterns
Economic globalization, combined with the globalization of information exchange, is likely to further spread ‘Western’ lifestyles and consumption patterns. Without a ‘dematerialization’ of these lifestyles, environmental gains from the dematerialization of production may be partially or fully offset by a growing demand for goods and services (e.g. travel, luxury goods and space). Given the global cultural dominance of the Western lifestyles, the developed countries may have to take the lead in adopting more sustainable lifestyles and consumption patterns for the rest of the world to follow.

Institutional conditions

3 For example, avoiding depletion of resources by keeping consumption below levels that would require long-term substitution of exhaustible resources and within the natural regenerative capacities of renewable resources.

4 For example, the intended levels and rates of change may be derived from targeted or critical levels of acid deposition, nutrient emission levels that prevent eutrophication, and natural mobilization levels of toxic substances.

To enhance the environmental transitions a particular set of institutional conditions is crucial because this will influence both environmental policies and the socioeconomic conditions required for these transitions to take place. A general prerequisite is a stable and well-functioning government structure; however, for various reasons this condition has not yet been met in many countries.

Internalizing environmental and social costs

An important institutional condition for the environmental transitions is to compensate for the tendency of markets to ignore long-term environmental and social costs by regulating conditions for production, trade and consumption (Andersson *et al*., 1995). However, policies and regulations also often stimulate the inefficient and/or unsustainable use of natural resources, for example, by providing for subsidies for the use of natural resources such as energy and water (World Bank, 1992; 1996) and through spatial planning and infrastructural development.

The internalization of environmental and social costs is complicated by unequal levels of economic development. Developing countries often have a weak position on world markets. The least developed countries are in particular often heavily dependent on a limited number of (low value-added) export products on markets were they have little or no bargaining power to set prices. This is, for instance, due to the substitutionability of raw materials and the involvement of large transnational corporations. As a result, many developing countries have experienced a deterioration in their terms of trade over the years, making it very difficult to include environmental and social costs in the prices of their products. The high level of indebtedness of many developing countries has stimulated governments to accept the sell off their natural resources at prices that do not allow sustainable reproduction. These problems will have to be addressed by international arrangements on trade and development (see Kox and Linnemann, 1994). However, apart from economic conditions, the incorporation of environmental and social costs is often even more hampered by a lack of adequate institutional arrangements for environmental and social regulation, monitoring and enforcement.

Strengthening institutions

To realize the environmental transitions, strengthening the institutional structures and capacities for environmental resource management at both the local and national levels is very important, especially in developing regions. At the same time, the economic globalization and the effects of global environmental change increasingly limit the effectiveness and efficiency of national or local policies, necessitating international policy development and coordination. It is therefore also essential to strengthen international institutional structures to enable a timely identification of and response to emerging problems, to coordinate policies effectively and to enforce international law. Given the nature of the environmental transitions and the interlinkages between environmental and development issues, these institutions will require a broad mandate to be effective (see below).

From the conditions indicated it is clear that the environmental transitions will not take place autonomously. In fact, it may be argued that in addition to the well-known demographic transition, and the environmental transitions mentioned before, a socioeconomic transition towards more social and international equity (including equity on the basis of one’s sex) is needed. An institutional transition towards more effective (global) governance, able to provide and maintain effective regimes to account for social and environmental costs in economic decision-making, is also necessary. In this respect, globalization of the market economy in particular poses a serious challenge to sustainable development, given present inequalities in the levels of development and the lack of effective structures for international governance.

Box 7.2 *The consequences of economic globalization*

There is no consensus on the consequences of current trends towards increasing economic integration of local markets into one global market, often referred to as *economic globalization.*

According to mainstream thinking in international economics, free trade will lead to an increase in overall global economic efficiency and welfare, both due to a more optimal economic allocation of production processes, given differences in factor endowment / factor prices, and stronger incentives for technological innovation. Technological innovations often also reduce the resource intensity of production processes. Initially, these technologies will be foremostly introduced in the more developed regions, but are likely to spill over to developing countries as a result of such aspects as foreign investments, standardization and price reductions. In this way, economic globalization may contribute to the environmental transitions.

From an ecological perspective economic globalization may be viewed rather differently. While trade helps to lift local resource constraints on economic development, it also implies more transportation and obstructs the maintenance of local material/nutrient cycles. Increased economic specialization may lead to more efficient, but at the same time ecologically more vulnerable production systems (e.g. mono-cultures) (Andersson *et al*., 1995). It has been argued that the resulting fiercer international economic competition will make it more difficult to internalize environmental and social costs, and will tend to lower environmental and social standards (The Case against Free Trade, 1993; Group of Lisbon, 1994). Fiercer competition may also lead to more interregional inequality and thus stimulate the unsustainable exploitation of natural resources, especially in developing countries. Efficiency improvements and specialization also has important consequences for employment, especially as free movement of labour remains largely restricted. Finally, like global environmental problems, economic globalization erodes the effectiveness of national environmental policy-making and accentuates the need for effective international governance.

7.3 Assessing regional challenges

The concept of environmental transitions can be used to help identify regional and global policy priorities for enhancing sustainable development. Because of different ecological, social and economic conditions (e.g. completed demographic transitions in Western Europe and continuing low levels of per capita energy consumption in Africa), not all transitions need be given the same priority in all regions. In fact, differences within regions may be greater than between several regions. On the basis of the analysis in this chapter, the following environmental transitions would seem to be most important for the various regions in order to achieve sustainability.

1. Africa. The African continent clearly faces the most difficult prospects due to its high rate of population growth and low level of economic development. The population of large areas of the continent suffer from ill health, characterized by high infant and maternal mortality, and low life expectancy and health expenditures. Particularly alarming is the still expanding epidemic of HIV infections and AIDS, with its associated sharp rise in tuberculosis incidence and mortality. With respect to future environmental problems, for North Africa many of the findings for West Asia apply (see below). In sub-Saharan Africa the key issues are the availability of sufficient land and water resources, which are increasingly affected by land degradation and depletion, while the expansion of agricultural land sharply reduces the remaining natural area. Given the projected deforestation and population growth also the present problems around fuelwood availability are likely to be substantially exacerbated. Climate change impact studies suggest that land and water resources in Africa are particularly vulnerable to climatic change, possibly including changes in the frequency of droughts. Uncontrolled urbanization is also likely to exacerbate urban environmental and social problems in specific areas.

***Table 7.2** Main regional challenges with respect to environmental transitions.*

Africa	land/food (productivity), water (efficiency), institutional conditions (effective governance), social conditions (alleviation of poverty)
Asia & Pacific	land/food (productivity), energy (efficiency), social conditions (alleviation of poverty)
Europe & former USSR	energy (efficiency/renewables), materials (efficiency/lifestyle change)
Latin America	energy (efficiency), social conditions (equity)
North America	energy(efficiency/renewables), materials (efficiency/lifestyle change)
West Asia	water (efficiency), land (productivity), social conditions (alleviation of poverty)

Food demand can theoretically be met by exploiting the opportunities for increasing agricultural yields, complemented by imports. However, even with higher yields and more imports, land conversion in the region is still expected to lead to a large decline in natural areas and therefore in biodiversity. Clearly, agricultural development combined with integrated water management is of the utmost importance for more sustainable development in the region. It has the potential to both enhance regional food security, to help alleviate poverty by providing employment and income, and to limit both the expansion and degradation of agricultural land. Moreover, it will slow down urbanization and fuel general economic development which, together with education, may stimulate the demographic transition. The risk of increasing world food prices due to an increased food demand, especially in Asia, makes investing in agricultural development all the more urgent. In that case governments of poor food-importing countries will face increasing difficulty in subsidizing food for the urban poor while at the same time lacking the means to improve local food production. A timely autonomous response of local farmers to higher world food prices may well be hindered or delayed by both infrastructural and institutional barriers (e.g. transport, price policies and a lack of investment capital). Therefore, to reduce the risk of food crises arising from both internal and external developments, urgent action is required. In order to realize land and water transitions, governments and donors face the challenge of setting up and implementing extensive investment plans for rural and agricultural development. Another challenge in many cases will be to strengthen government structures and remove institutional barriers.

2. Asia. The current rapid economic development is expected to continue and lead to major advances in human health and well-being. The negative environmental effects of high population densities combined with rapid industrialization already apparent are projected to increase in the future if appropriate investments in environmental protection are not made. Rapid industrialization is expected to lead to severe urban air pollution and regional acidification, and to make Asia a major contributor of greenhouse gases. Increased food demand is expected to lead to a further encroachment on the remaining natural area, exacerbated by land degradation, the possible effects of climate change and continuing urbanization. To sustain development opportunities in the region and prevent further environmental degradation, changes in the long-term characteristics of the energy system require high priority, especially in East and South-East Asia. In the South Asian subregion, alleviating poverty, facilitating a slowdown of population growth and preserving agricultural land are crucial. Agricultural development to raise productivity remains a key challenge throughout the region, especially since the expected food imports due to insufficient regional food production could have profound implications for food security in other parts of the world.

3. Europe and the former USSR. While prosperity will continue to grow and populations will stabilize or decrease, unemployment will probably remain a key socioeconomic issue. In terms of the environment, projected increases in agricultural productivity should, theoretically, make it possible to return agricultural land to natural areas, especially in Western Europe. However, increased demand from other regions is likely to limit this. Moreover, natural ecosystems are threatened by fragmentation resulting from infrastructure development, continued expansion of urban areas, local and regional pollution and climate change. Notwithstanding progress in national and regionally co-ordinated pollution control and abatement due to the high density of population and economic activity (including intensive agriculture), environmental improvements in Europe may be insufficient to prevent further degradation. Additional efforts will be needed. Given Europe's high per capita demand for environmental resources such as energy and raw materials, and its large share in past and projected future emissions of greenhouse gases, the energy and raw material transitions (energy efficiency, renewable resources and the 'dematerialization' of production and consumption) present a great challenge in the context of global sustainability. These transitions will at the same time contribute to the resolution of local and regional environmental problems, such as urban air pollution, acidification and waste, notably in Eastern Europe and the former USSR.

4. Latin America. The rich natural and human endowments of the region have the potential to lead to major advances in human health and well-being in the region, as illustrated in the Conventional Development scenario. In principle, opportunities for increasing efficiency in agriculture permit a slowdown of the expansion of agricultural land and the current high rate of deforestation in the region. This would result in significantly fewer negative effects for biodiversity than presently foreseen. However, depending on developments in other parts of the world, in particular Asia and Eastern Europe, South America may become a more important exporter of food, leading to an additional need of agricultural land. Moreover, a major concern in the region is the inequitable distribution of wealth, which has not only social, but also environmental implications, and may continue to contribute to poverty-related degradation of land resources and natural area. The negative social and environmental implications of rapid urbanization also deserve special attention. The rapid industrialization in some subregions is likely to lead to both increasing local and regional environmental problems as a result of urban pollution and acidification. Therefore the clean and efficient use of energy will deserve increasing attention.

5. North America. As in Europe, improvements in agricultural yields tend to free up agricultural areas for nature development. However, like Europe, increased food demand from developing countries may forestall this development. While the total area of agricultural land may not change much, due to climate change the location of agricultural activities may shift considerable from west to east at the expense of forested areas. Natural areas may further suffer from increasing pressures due to persistent urban sprawl, air pollution from industry and transport, and climate change. As it is one of the main emitters of greenhouse gases, the region, like Europe, is in a logical position to spearhead efforts to mitigate climate change. Equally, the energy and materials transitions deserve to be given a high priority.

6. West Asia. The situation in West Asia is particularly problematic. The scarcity of fresh water resources - and to a lesser extent land - is expected to lead to increasing competition for these resources with potential implications for migration and social stability. Integrated regional water management therefore needs to be given a high priority. The availability of rich natural resources

- notably oil and gas - may permits some countries to import food and enables investments in increasing the efficiency of water usage (e.g. the re-use of drainage water for irrigation); other less endowed countries may have more difficulty in financing food imports and making the necessary investments in their water and agricultural systems.

7.4 Policy strategies to enhance sustainable development

It is beyond the scope of this chapter to attempt to add to the many thematic recommendations of Agenda 21 or to recommend priorities for specific policy responses. Instead, the focus here is on a few policy strategies to enhance the environmental transitions outlined above. These strategies involve (a) integrating environmental and socioeconomic policies (b) integrating environmental policies and (c) promoting efficiency, access to technologies and specific structural changes.

Integrating environmental and socioeconomic policies

In the foregoing analysis, which looked at sustainable development merely from an environmental perspective by focusing on environmental transitions needed, it was already emphasized that these transitions cannot be realized without policies providing the supportive socioeconomic and institutional conditions. Likewise, sustainable development cannot be achieved by policies designed merely to maximize material economic growth or to pursue equitable social development alone. This implies a balanced focus on economic, social and environmental issues. It includes not only the mitigation of poverty and inequalities in regions such as Latin America, Southern Asia and Africa, but also the institutional developments that are needed to address the problems adequately, like especially - but not exclusively - in Africa. In northern regions present environmental problems are closely connected with lifestyles, suggesting that a fundamental discussion on these will eventually be difficult to avoid.

For pursuing sustainable development its essential that the environmental, economic and social perspectives on development are integrated. In fact, since social and economic development has a higher priority than environmental protection in many countries, it is vital to integrate environmental considerations into social and economic planning.

At the policy level this implies, first, that policies for the various issues should not be developed separately but rather coherently, based on an integrated assessment of how they are interlinked, and that different policy goals could be furthered by common policies. Second, economic, social and environmental issues should be more equally weighted in policy-making, resulting in balanced investments for both social, economic and (specific) environmental measures.

One new way of monitoring this balance is an approach developed by the World bank which takes into account the development of various forms of national capital (environmental, social and economic) over time as a tool to assessing to what extent development patterns are sustainable (World Bank, 1995a; 1996). (See also Box 7.2.)

Linking issues: creating new opportunities for more effective policies

A consequence of linkages between economic and environmental changes (through globalization, and the disturbance of element cycles as well as the land - water interaction) is that while economic, social and environmental systems are subject to multiple stresses, there can also be responses identified which address multiple environmental issues concurrently. Ignoring these linkages results in isolated response options which may be inefficient (by missing opportunities for synergy) and/or ineffective (e.g. by improving one problem but worsening another). From the assessment in this chapter two important candidates for policy integration would seem to emerge:

Integrated energy policies
A large proportion of environmental problems related to the disturbance of life-sustaining element cycles, such as climate change and acidification, stem from the energy sector. The same holds for other forms of air and water pollution, and the production of solid wastes. These problems affect all levels, from the local to the global. Since energy is one of the key requirements of economic development in all regions, an international political focus on the transition required in the energy system could provide more effective policy options than separate negotiations on individual environmental problems, not in the least because energy is higher on the political agenda than environmental protection.

Integrated landuse policies
The lack of sufficient land and water of adequate quality has been identified as one of the potential future barriers to development in many regions. The nature of the problems is global and there is one key common driving force - agricultural development. This suggest that creating a forum for the debate on how to increase agricultural productivity while protecting the natural environment and managing sustainable water resources, may create new opportunities for international action. Such opportunities may be missed in separate negotiations on biodiversity, desertification and forests. The analysis presented in this work suggests that to ensure worldwide food security, sustained increases in productivity are essential. A similar programme for increasing efficiency is crucial for sustainable water use.

After the Green Revolution and the **Water Decade**, a **Land Decade**, a **Water Revolution** and a **World Energy Initiative** may now be needed to promote and co-ordinate such changes.

Promoting efficiency and technology transfer: creating more wealth with less material input and environmental pressure

Given the assumed growth of the world economy between 1990 and 2050, a 4 to 5-fold increase in overall ‘efficiency’ is needed just to keep environmental pressure at its current level. Of course, in many cases this will not be sufficient to prevent further degradation of environmental resources. Depending on assumptions made with respect to population growth, economic growth,

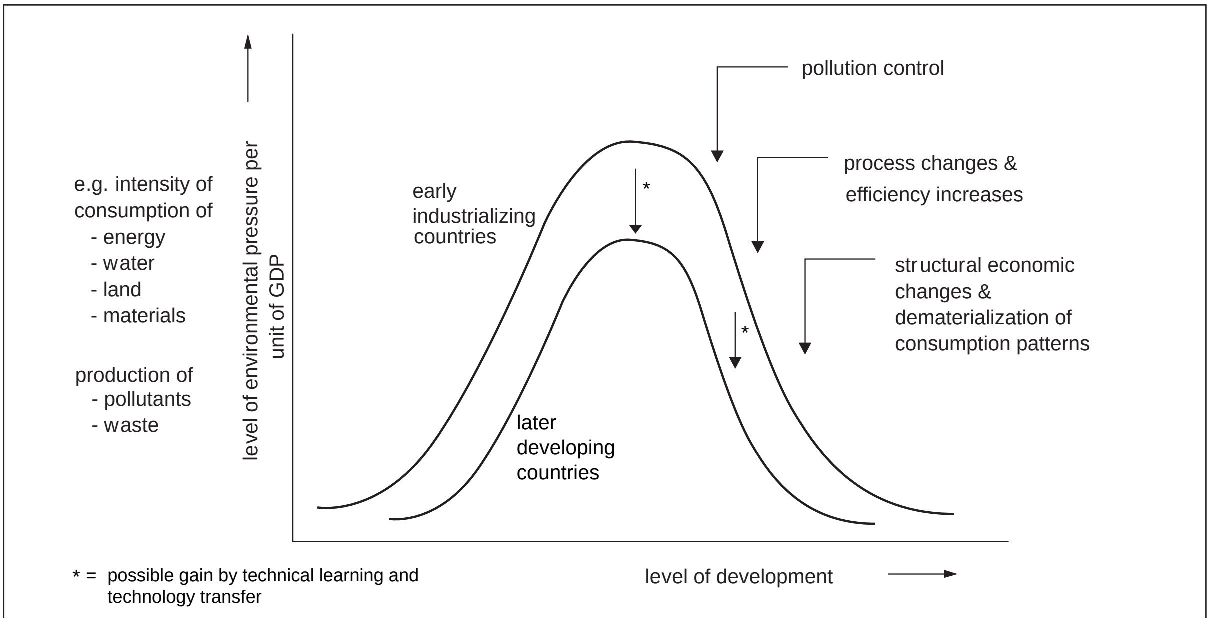

Figure 7.2. *Environmental efficiency transitions*

and levels of the sustainable use of various natural resources, the actual efficiency improvements required within the next half century are estimated to be in the range of 5 to 20-fold (Opschoor, 1994; RMNO, 1994). This can only be achieved by increases in technological efficiency and the 'dematerialization' of production and consumption. This 'efficiency transition' can be illustrated by the bell-shaped curves in Figure 7.2. As already stated, in the early stages of industrialization, pressure on the environment rises in a typically rapid way, followed by decreasing growth in pressure in the later stages of development and eventually an absolute reduction in pressure (e.g. Greadel and Allenby, 1995; World Bank, 1995a).

The shape of the curve is influenced by both a structural shift from the initial growth of (relatively polluting) heavy industries to support the expansion of infrastructure, buildings and production capital towards (cleaner) lighter industries and services (as part of the economic transition), as well as by the application of cleaner and more material and energy-efficient technologies. This latter development is thought to be the result of a greater concern for environmental quality that comes with rising incomes (World Bank, 1992). This type of environmental transition has been observed in most industrialized countries. However, it is not yet discernible for all kinds of environmental problems (e.g. waste and greenhouse-gas emissions) and may partially be the result of an international reallocation of industrial production (e.g. to the so-called Newly Industrializing Countries)[5].

It has been argued that by learning from experience gained in the industrialized countries, regions that are currently in the early stages of industrialization can limit or avoid serious environmental degradation by adopting an appropriate combination of preventive and remedial social, economic and environmental policies. In this way, these regions may combine a transition to higher income and welfare levels with a transition towards sustainable resource management (see e.g. Grübler and Nowotny, 1990). In this respect the early adoption of efficient and clean technologies has been advocated, especially in relation to energy production and use (e.g. Reddy and Goldemberg, 1991). Although energy and material efficiencies can still be improved considerably in the developed countries, the transfer of efficient technologies to developing countries is probably even more important because this is where most of the future expansion of industrial capacity is likely to take place.

The potential of these strategies can be illustrated by both experience from the real world and explorative model exercises (see following sections).

Experiences with pollution prevention: the UNEP Clean Production Programme
The potential for reducing environmental pollution in an economically viable way is clearly illustrated in the many projects shown within UNEP Industry and Environment Cleaner Production Worldwide Programme. In contrast to the traditional use of end-of pipe technologies to abate environmental pollution, the cleaner production strategy promotes a preventive approach as in most cases being economically more attractive and ecologically more effective. It is directed at the continuous improvement of processes and products to reduce the use of resources and energy, to prevent the pollution of air, water and land, to reduce wastes at the source and to minimize risks to the human population and the environment.

[5] As argued by Arrow *et al.*(1995): first, this type of transition has only been shown to be valid for pollutants involving local short-term costs (e.g. sulphur oxides, particulates, coliforms) and not (yet) for the accumulation of stocks of waste or for pollutants involving long-term and more dispersed costs (such as carbon dioxide), which often increase with income levels. Second, the relationship is less likely to hold wherever there are significant feedback effects on resource stocks, such as those involving soil and its cover,and ecosystems. Third, the curve says nothing about the system-wide consequences of reductions in emissions (regional transfer of pollutants or polluting processes). Fourth, the downward movement in the curve was due to local institutional reforms and measures taken regardless of the international and inter-generational consequences.

It implies (UNEP/IE, 1996):
1. *Product Modification*: modification of the product characteristics in order to minimize the environmental impact of the product during or after its use (disposal), or to minimize the environmental impact of its production
2. *Input Substitution*: substitution of input materials by less toxic or renewable materials, or by adjunct materials with a longer service lifetime
3. *Technology Change*: replacement of the technology, the processing sequence and/or the synthesis pathways in order to minimize waste and emissions generation during production
4. *Equipment Modification*: modification of the (existing) productive equipment and utilities in order to run the processes at higher efficiency, and lower waste and emission generation, rates
5. *Better Process Control*: modification of the working procedures, machine instructions and process record-keeping in order to run the processes at higher efficiency, and lower waste and emission generation, rates
6. *Good Housekeeping*: appropriate provisions to prevent leaks and spills and to enforce the existing working instructions
7. *On Site Re-Use*: re-use of the waste materials in the same process or for another useful application within the company
8. *Production of Useful By-Products*: modification of the waste generation process in order to promote re-use or re-cycling outside the company.

In the short term, potential gains can be exploited through the improvement of management skills. Over the longer term, equipment modification, or even a leap to new technologies, inputs and products might be needed. Cleaner production leads to reductions of resource use and in the amounts of waste and pollutants in the order of often 40 to 70 per cent while delivering substantial economic benefits at the same time (UNEP/IE, 1995, 1996). Of course, the approach does require the availability of sufficient technical know-how and investment capital, which, especially in developing countries are not always readily available. Therefore the provision of long-term investment capital and technical assistance to facilitate the transfer are important prerequisites for making his strategy successful worldwide. In addition, national governments will need to stimulate and support this strategy by giving priority to pollution prevention, setting long-term goals in addition to short-term standards, applying regulations, removing institutional barriers and creating economic incentives (UNEP/IE, 1996).

Exploring the potential: some modelling exercises

To explore the global potential for reducing the pressure on the environment by promoting efficiency several quantitative analyses were carried out using the regionally detailed IMAGE 2 model. This was done for both energy use and food supply by exploring the positive effects on resource use and environmental degradation. A convergence of the technological efficiencies between the developed and developing regions over a 20-year period was used in this exploration. The exercise simulates the application of so-called ‘best available technologies’ all over the world as a result of (extremely fast) transfer of technology.

To illustrate the possible impact, the result of the model exercise is compared with a baseline scenario resembling the conventional development scenario (IMAGE-2 baseline A; See Alcamo *et al.*, 1996). The same medium population growth and medium economic growth assumptions were used in all calculations.

For the ‘technology transfer variant’ (variant 1) it is assumed that, for both energy and agriculture between 1990 and 2010, the developing regions would reach the level of marginal efficiency of the developed regions. Within the energy sector it is assumed, for example, that all newly built industrial plants and power stations all over the world will be as efficient as the best available

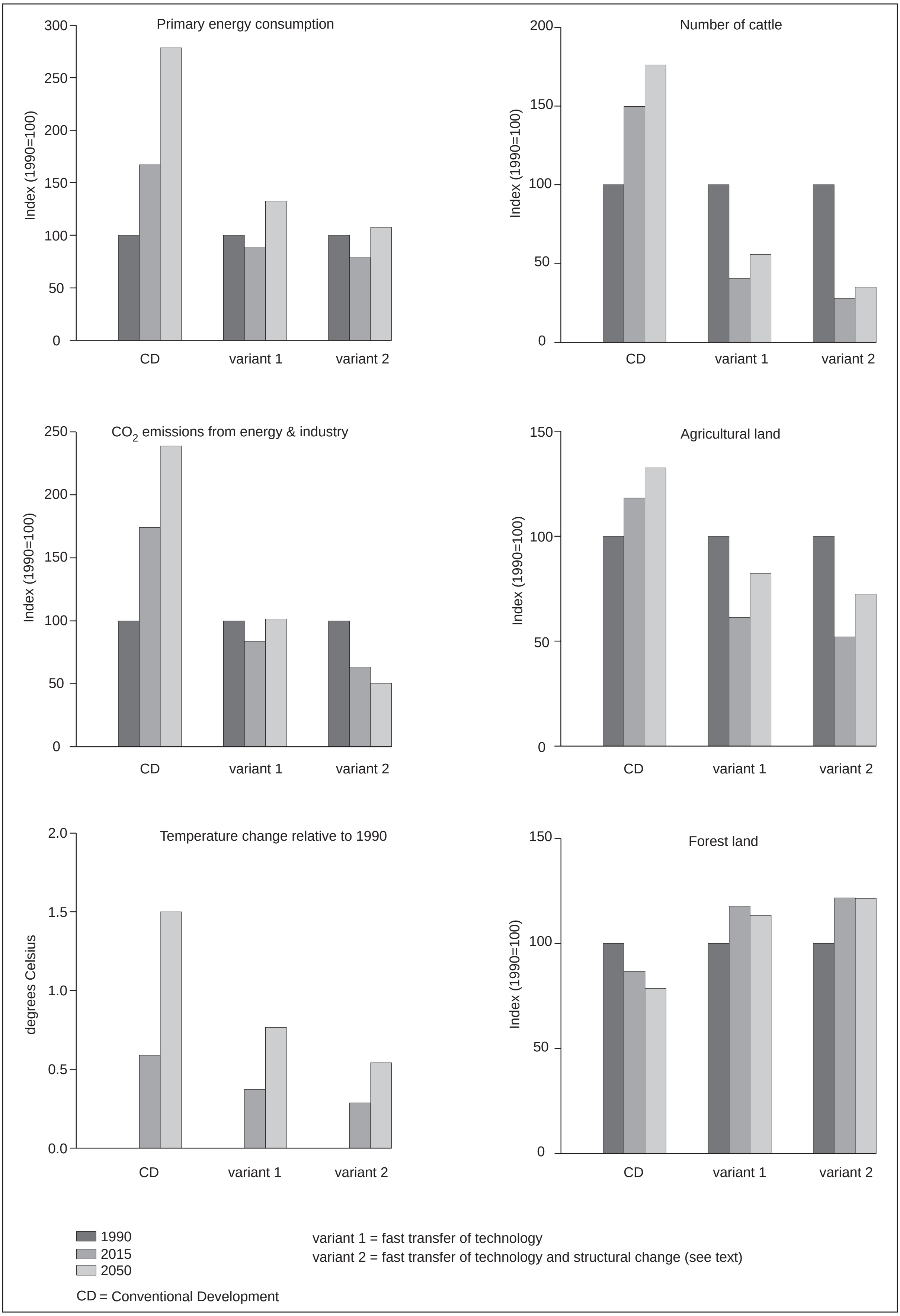

Figure 7.3. *Potential environmental gains of two different policy strategies*
Source: Alcamo *et al*. (1996).

technology. Within the agricultural sector it is assumed, for example, that animal husbandry and management practices in developing regions converge to the higher productivity level of the developed world.

As is shown in Figure 7.3, the large increase in energy consumption as seen in the baseline scenario (CD) now almost disappears. The carbon dioxide emissions from energy expenditure and industry show an even larger reduction than for energy consumption. The number of cattle is projected to decrease substantially because of the introduction of agro-technological improvements raising animal productivity. By 2050 the number of cattle is about half the current number. The projected increase of about 30 per cent in agricultural land use under the baseline scenario in 2050 turns into a decrease of about 20 per cent . The assumed convergence of agricultural efficiencies results in an increase in forest area of about 20 per cent instead of a similar decrease expected under the baseline scenario.

The rate of technology transfer assumed in the modelling exercise is extremely high and should be regarded as unfeasible. Transfer of technology requires not only enormous funds, but also a social and cultural environment susceptible to the technologies suggested and an educational, technical and physical infrastructure able to sustain its implementation and maintenance. Clearly, these conditions cannot be realized in such a short time span. However, the exercise does show the large technical potential for reducing the pressure on the environment while maintaining economic growth.

It is being argued, both in the North and the South, that in addition to increases in technological efficiency, changes in production and consumption patterns are of major importance for sustainable development. This is because environmental gains through improvement in levels of efficiency and pollution control will be offset by economic growth if no structural changes are made. As shown in Chapter 4, future demand for agricultural land and the associated loss of natural habitat is strongly related to dietary patterns, especially the assumed increase in the demand for animal products as incomes rise. Given the loss of efficiency in converting vegetable products into animal products, the overall efficiency of the global food system could be substantially improved were the overall consumption pattern to evolve towards less meat and dairy-intensive diets than assumed in the Conventional Development Scenario. In production a structural shift toward the use of renewable resources and recycling is advocated. This also applies to the use of renewable energy resources, like modern biomass.

The potential contribution of such structural changes was also explored by an additional modelling exercise (variant 2), representing a ‘structural change scenario’.

Apart from the convergence in technologies assumed in variant 1, the following assumptions were made: the consumption of meat and dairy products in de developed regions is gradually reduced by 50 per cent between 1990 and 2010; for the developing regions, the per capita consumption of meat and dairy products is kept at its 1990 level; the market share of renewable and biomass is assumed to increase to 55 per cent in 2050 (compared to 20 per cent in the baseline and technology transfer scenario); population growth and economic growth are kept the same as in the baseline scenario.

The addition of structural changes in the energy system and in dietary consumption patterns results in an additional reduction of environmental pressures and impacts, although to a lesser extent (see Figure 7.3). In 2050 the carbon dioxide emission of the ‘fundamental change variant’ is about 50 per cent of the 1990 level and only 20 per cent of the baseline scenario (CD), while these figures are 66 per cent and 40 per cent, respectively, for the ‘technology transfer variant’ (variant 1). Also the amount of agricultural land is further reduced than in the ‘technology transfer variant', even though more arable land is needed for the additional production of modern biofuels (which offsets some of the gains of the lower consumption of animal products). The structural shift to biofuels results in continued decrease in carbon dioxide emissions. In the case of agricultural land, environmental pressures (slowly) re-link with economic and population growth in both variants if no further increase in technological efficiencies or structural shifts are assumed. This highlights the importance of policies slowing down global population growth faster than under conventional development.

Although the modelling exercises are only a preliminary attempt to show the potential impacts of environmental strategies and cannot be considered realistic assessments, the results indicate that reductions of environmental pressures in the order of the factor 2 to 5 seem, at least technically, feasible. Improvements by another factor of 2 (so 4 to 10 in total) may be possible if the efficiency of technology efficiency continues to increase by 1 - 2 per cent per year and if population growth slows down faster than assumed as a result of targeted policies and a general improvement of socioeconomic conditions.

The modelling exercises presented may serve as a starting point for more elaborated future modelling and scenario analyses on the impacts of different policy strategies and measures. These should be part of the construction and evaluation of true alternative policy scenarios for future GEOs.

7.5 Cost indications of policies to promote sustainable development

Section 7.1 stated sustainable development as requiring, among other things, transitions in the various environment-related areas of human behaviour like energy and material use, and the use of land and water resources. In this section a preliminary estimation will be made of the amount of costs involved in bringing about these transitions, but no attempt will be made to make a cost/benefit analysis. This is because the benefits of environmental measures are even more difficult to assess and include assets like the preservation of nature or saving human life years, which are difficult to valuate in simple monetary terms.

However, it is estimated that the environmental damage in developing countries, Eastern Europe and the former USSR already greatly exceeds 3 per cent of the GDP, not including loss of natural phenomena such as biodiversity. In industrialized countries environmental damage is generally estimated to be below 2 per cent of GDP. Recent estimates for the costs of future damage due to climate change range from 1 - 1.5 per cent for the industrialized countries and 2 - 9 per cent for developing countries (IPCC, 1996).

In the industrialized countries the costs of pollution control and abatement (the first steps in the materials transition) amount typically to 1 - 2 per cent of GDP in these countries (OECD, 1993). The costs of implementing environmental policies in these developing regions are uncertain, but many low-cost opportunities exist. In many developing countries and former socialist planned economies prices of energy and other natural resources were until recently heavily subsidized, resulting in their inefficient use. Removal of these will not only stimulate a more efficient use of energy and materials at no economic costs, but also free substantial governmental funds for possible spending on environmental and social policies (World Bank, 1992, 1996; OECD, 1993).

Estimating the costs of the indicated environmental transitions indicated is complicated by many factors. First, many organizational and institutional dimensions of the transitions cannot be expressed in monetary terms. Second, both the nature and the necessary extent of measures to realize these transitions cannot be determined unambiguously: in most cases there are many options, while the necessary level of action is difficult to determine objectively (see also Box 7.1). Third, the costs of measures is dependent on the assumed baseline or autonomous developments and the rate of implementation. Fourth, the level of costs is determined by the definition of costs used, i.e. whether economic benefits are taken into account or not and what part of the investment costs should be accounted for as environmental costs in applying cleaner and often economically attractive technologies instead of add-on end-of-pipe measures. Fifth, a bottom-up, micro-economic evaluation of the costs of the environmental measures may lead to very different outcomes than a macro-economic assessment because they do not take into account macro-economic effects at the national and international levels. This is important because policies aimed at land and water transitions may affect overall economic development or the effectiveness of policies directed at other transitions[6].

The estimates of the costs of measures to enhance the various environmental transitions given below are solely based on estimates reported in various global, regional and thematic studies (see Rijsdijk, internal RIVM memorandum). Global estimates of environmental costs are available from the World Bank: 'World Development Report 1992'(World Bank, 1992) and the World Watch Institute's 'State of the World 1988' / 'Full House'(WWI, 1988/1995). One regional study 'Middle East and North Africa Environmental Strategy' was also included (World Bank, 1995b)[7]. Thematic studies used are 'A New Asssessment of the World Status of Desertification' (Dregne *et al*., 1991) (on the land transition), 'The Decade and Beyond' (Christmas and de Rooy, 1991), 'Proceedings of the Ministerial Conference on Drinking Water and Environmental Sanitation' (Majumdar, 1994) (on the water transition) and 'Climate Change 1995 - Economic and Social Dimensions of Climate Change' (IPCC, 1996) (on the energy transition).

The various studies only cover a selection of measures envisaged to enhance the environmental transitions. Many measures are just enough to control or reverse environmental damage, like land rehabilitation. Thus the measures cover only the starting phase of the transitions aimed at (see Table 7.3). For that reason they are likely to be at the low end. On the other hand, the cost estimates do not take the economic benefits into account. The studies use different costing methodologies. The reported costs given in Table 7.3 are additional costs expressed as per cent of current GDP and annualized on the basis of an implementation period of 10 years.

According to the limited literature base used, the total additional costs of the implementation of the selected packages of environmental measures to enhance sustainable development is in the range of 0.2 to about 1 per cent of global GDP. The World Bank and WWI have also calculated costs for social and institutional measures to support sustainable development that should accompany the environmental measures. These include additional expenditures for family planning and improved school enrollment rate for girls (World Bank, 1992) and improved health care and debt relief services for the least developed countries (WWI, 1995). If these costs are included, global costs are raised with 0.5 to 1.3 per cent of global GDP.

[6] Therefore, for future studies an integrated macro-modelling approach analyzing the effects of policies on the environment and the economy at both the regional and global levels will be used. Most modelling tools for this kind of analysis focus on the developed regions and lack sufficient realism with respect to other regions. One model taking all regions into account is the WORLD SCAN model, developed by the Netherlands Bureau for Economic Policy Analysis (Geurts *et al*., 1994). This a global macro-economic model with 10 regions and 7 sectors used to evaluate sectoral investments and taxation policies aimed at environmental transitions. At present, efforts are underway to link this model with the IMAGE model to further enhance its capacity for integrated environmental economic analyses.

[7] Two other studies on the Asian region were also available, but could not be used for technical reasons: 'Towards an Environmental Strategy for Asia (World Bank, 1993) and 'Financing Environmental Sound Development' (Asian Development Bank, 1994)

Table 7.3 *Estimated global costs of policy measures promoting transitions towards sustainable development*

		WWI (1988, 1995)*	WB (1992)	Various sector studies		Lowest	Highest	M N A region WB (1995)
		10^9 US$ per year						
Land	land conservation (including extension services)	24	15	5.7 Dregne et al. (1991)**		5.7	24	1.25
	land rehabilitation (e.g. planting trees)	7	2.5	26.7 Dregne et al.(1991)**		2.5	26.7	–
	conserve biodiversity	–	2.5			2.5	2.5	–
	agricultural research on soil processes	5	5			5	5	–
	develop sustainable agricultural methods		–			–	–	–
	improve land use planning	–	–			–	–	–
	shift towards less animal food	–	–			–	–	–
Subtotal land transition		36	25	32		16	58	1.25
Water	provide all people with clean water	–	6	7.7 Christmas and De Rooy (1991)	5.2 Majunder (1994)	5.2	7.7	2
	provide all people with proper sanitation	–	4	18 Christmas and De Rooy (1991)	16.9 Majunder (1994)	4	18	****
	efficient use of water resources	–	–			–	–	–
	institutional efficiency reforms	–	+			–	–	–
Subtotal water transition		–	10	26	22	9	26	2
Energy	raise efficency of energy use	55	+	+ IPCC (1996)		–	55	–
	shift from fossil fuels to renewables	30	3.5	+ IPCC (1996)		3.5	30	–
	shift to low carbon fuels (e.g. natural gas)	–	–	+ IPCC (1996)		–	–	–
	remove greenhouse gases	–	–	+ IPCC (1996)		–	–	–
	taxes on fossil fuels	+	–	+ IPCC (1996)		–	–	–
	research on climate change	–	+	+ IPCC (1996)		–	–	–
Subtotal energy transition		85	3.5	***		3.5	85	–
Materials	reduce emissions from electric power generation	–	7			7	7	0.45
	reduce emissions from road transport	–	10			10	10	0.65
	reduce emissions from industrial proccesses	–	12.5			12.5	12.5	1.95
	reduce material intensity	–	–			–	–	–
	change production technologies	–	–			–	–	–
	close material cycles	–	–			–	–	–
	use less harmful substances	–	–			–	–	–
	municipal solid waste management	–	–			–	–	0.5
Subtotal materials transition		–	29.5			29.5	29.5	3.55
Total		121	68			58	199	6.8
		%						%
Total relative to 1990 GDP (world resp. MNA)		0.58	0.32			0.28	0.95	1.43

Sources
See references in the table. Compiled by Rijsdijk (internal RIVM memorandum, 1996)

Notes
* For the WWI report, the costs in the tenth year of the 'sustainability program' are mentioned
** Not additional
*** Not additional; not used in 'lowest-highest'. Subtotal estimate 0.8 - 2.2 % of world GDP
**** Included in estimate for clean water

Signs and abbrevations
\+ Measure mentioned, but no cost estimation
– Measure not mentioned
MNA Middle East and North Africa
WWI World Watch Institute
WB World Bank

Putting these cost estimates product in perspective, they can be compared with the global annual expenditures of 5.2 per cent of the world for education, 3.2 per cent for military purposes, 0.3 per cent for Official Development Aid and 0.003 per cent for the Global Environment Facility.

The comparison shows that the costs are not very high, but much higher than present funds available for international development assistance. Most of the funds will have to come from domestic government sources, development banks and commercial sources. As indicated, considerable public funds could be raised and private investments in efficiency measures induced by just removing or reforming subsidies on energy, other natural resources and environmentally damaging inputs or practices (World Bank, 1992; 1996).
The global cost estimates mask the fact that environmental costs as percentage of GDP are much higher for developing regions than developed regions. Especially with respect to the land and water transitions, most measures will have to be taken in the developing regions. As a result costs for low- and middle-income countries are estimated to range between 1.2 to 4.2 per cent of their GDP. The policy package discussed by the World Bank results in additional costs for developing countries of 2 to 3 per cent of their future GDP (World Bank, 1992). An acidification study commissioned by the World Bank (Foell *et al*., 1995) showed that in order to apply Best Available Technologies as to avoid to a large extent the exceedance of critical sulphur deposition in Asia, reduction measures costing 90 billion US dollars would be needed by 2020. This corresponds to 0.6 percent of the region's GDP, but would amount to 1.7 per cent of GDP in the case of China.
This problem also holds for the so-called economies in transition, as can be illustrated by another study commissioned by the World Bank (Bollen *et al*, 1996). It indicates that economic restructuring in Central and Eastern Europe, equipping all new industrial installations with standard Western European technologies, would require yearly investments of 175 billion US dollars in the period 1995 - 2010. This would involve an annual savings rate of 15 to 20 per cent of their total GDP in the same period. This would result in substantial, but not always sufficient, reductions in the emission of most pollutants. Replacing all installed (old) capital with standard modern technologies, reducing emissions to more 'sustainable' levels, would require an additional 50 billion US dollars a year. Although such a restructuring would be both economically and environmentally sound, it seems unlikely that without substantial external funding these policies will be readily implemented. (However the study also indicated that in this case a sensible and relatively low cost start could be made by first addressing local emission sources, thereby reducing the most urgent health risks up front).
So while the overall global costs of policies to enhance the environmental transitions by a few per cent of global GDP do not seem to be prohibitive, they may be so for the non-OECD regions, where these costs are relatively high and day-to-day socioeconomic needs are more pressing than in the OECD countries.

7.6 Conclusions

If the world would develop according to the conventional development scenario analyzed in this report, many environmental and social goals stated in Agenda 21 for achieving sustainable development will still not be met. Substantial policy efforts will be needed to realize environmental transitions towards more sustainable global and regional development than in the Conventional Development scenario. However, policy priorities will differ with the region.

In general, integration of environmental, economic and social policies, as well as of policies for various environmental issues (e.g. focusing on sustainable energy use and sustainable agriculture) and the promotion of clean production and efficiency improvement by technology transfer and structural change in production and consumption patterns seem important strategies for making progress in implementing Agenda 21.

The envisaged environmental transitions can only be realized if both socioeconomic and institutional conditions are met, like the reduction of social and gender inequality, dematerialization of consumption patterns and effective regimes for incorporating environmental and social costs in economic and political decision-making. In this respect, investments in economic growth, social services and environmental protection need to be carefully balanced.

A preliminary global analysis of the additional costs of policy measures to enhance the various transitions seems to indicate that these are likely to be in the order of a few per cent of global GDP. These levels are substantial but not prohibitive, and, in most cases, will pay off well given estimates of present and future levels of environmental damage. However, for developing regions, the costs as a percentage of their GDP will be substantially higher. Without substantial external support these costs are likely to forestall the implementation of many measures. Therefore, the willingness of the developed regions to share in the costs of these investments seems essential for making progress towards a more sustainable common future. Moreover, especially in the case of global problems, like climate change, the developed regions bear a special responsibility due to their historical contributions to these problems and will probably have to take the lead in encouraging other regions to contribute to the solution as well.

The assessment of response options and the costs of transitions towards a more sustainable pattern of development in this chapter has only been a first attempt to help policy-makers in setting policy priorities and developing effective strategies at a global and regional levels. Clearly, there is much room for a further elaboration and improvement of the assessment. For future reporting it is envisaged not only to develop a set of different baseline scenarios, but also to assess policy options and their economic implications on the basis of well-defined policy scenarios. Moreover, future assessments will profit from the availability of a more integrated and consistent analysis framework resulting from linking demographic, environmental and economic models presently under development.

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INTRODUCING THE APPENDICES: THE FORECASTING PROCESS

The integrated and quantitative approach of this contribution to the Global Environment Outlook is to a large extent based on the application of comprehensive global change modeling, most notably of the IMAGE, TARGETS and RAINS models. To enable forecasts for the coming decades, these simulation models need a wide variety of core data sets on the present and past ‘state of the world’ as well as coherent sets of assumptions about possible developments in the future (scenarios).

Core data give information about the total of economic, demographic and environmental ‘state of the world’. Such data typically are collected by statistical offices at the country level, and reported to UN and other international agencies. These include population numbers, economic production, temperature and precipitation, for example, and are assembled and published by organizations such as UNSTAT, UNDP, FAO, WMO, the World Bank, the World Resources Institute and many others. Other core data sets are derived through processing of remotely sensed measurements from satellites such as LandSat, AVHRR or NIMBUS so as to derive information on, for instance, land cover or ozone depletion.

For GEO and related global assessments, data are needed for longer historical periods and sometimes with high geographical detail. Certain data may even have to go back to 100 years ago to enable forecasts for the next 100 years. Many data layers, like land cover, air emissions or population density are geographically so highly variable that spatial resolutions have to be smaller than the land mass of the countries, e.g. rectangles of 10 x 10 km. Such data is produced by applying image processing and geographical techniques like spatial interpolation and overlaying to one or more existing core data sets. For example, population density at 5 min spatial resolution can be generated by combining subnational population numbers, location and size of cities, transport networks and land use within a Geographic Information System. Temperature and precipitation are derived through interpolation of long-term data from meteorological stations and conversion to gridded surfaces. Emission volumes are often calculated by applying emission factors to the main sources and processes of emissions, like traffic and industrial production, while made geographically explicit by distribution according to population numbers. The complex processing of base data to derive such *value-added* data sets as high-resolution population density, air emissions or land cover make the distinction between data and models somewhat less clear-cut. However, there remains the principal distinction between data - that are intended as an approximation of reality - and outcomes of scenario analysis - which are conditional statements.

Scenarios relate to demographic, economic and technological developments for the future, like population growth and energy efficiency. The principal difference between data and scenarios is the conditionality of the latter: the future cannot be known and different scenarios depict different futures. However, only one such future state, the Conventional Development scenario, was used for the first GEO, being the only one now available for the envisaged analysis.

Integrated ***models*** are tools to analyze interrelated environmental issues such as climate change, acidification, and pressure on land, water, or natural habitat. These models combine a wide variety of input data and scenarios in order to analyze the issues in question.

This forecasting process can be depicted as in Figure A.1.

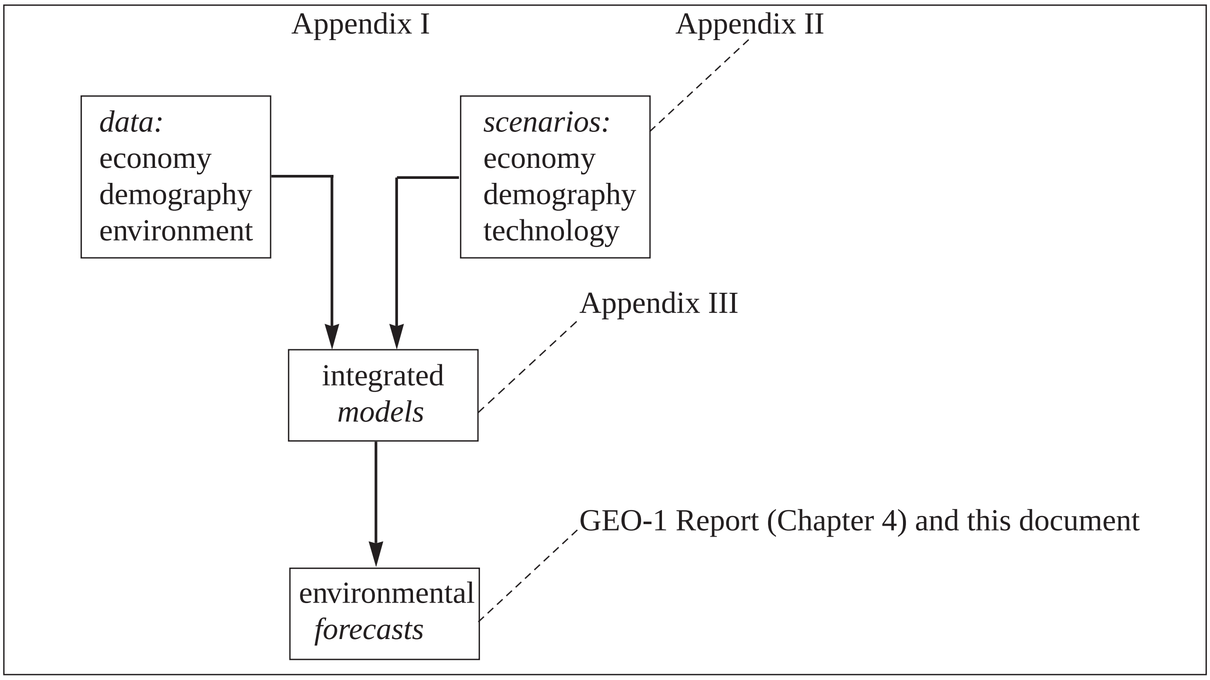

Figure A.1. *Schematic representation of the forecasting process*

The appendices list and describe each of the three elements i.e. data, scenarios and models, which underlie the environmental forecasting results of GEO. These elements are further elaborated and put in a wider perspective as part of the GEO process through three international working groups: the IEA/GEO Data Working Group, the Global Scenario Group and the Global Modelling Forum for Sustainable Development.

Core data sets for current modelling work at RIVM are presented and described yearly in the RIVM Catalogue of International Data Sets (Van Woerden et al., 1995). An overview of such data sets is included here as **Appendix I**. Listed are the currently used and most important global and regional data sets, which serve as input to the model-based analysis, with their major characteristics i.e. source, time period, geographic coverage and spatial resolution. For more information on such (meta-)data, contact Jaap.van.Woerden@rivm.nl.

The broader *data needs* for integrated environmental assessments, resulting from an internal RIVM survey in 1994, is also included in Van Woerden et al., 1995. At an aggregated level, these ‘core data needs’ match, to a large extent those identified through the International Symposium on Core Data Needs for Environmental Assessment and Sustainable Development Strategies (UNDP/UNEP, 1994). Together with inputs from other global environmental reports, the RIVM overview served as input for the IEA/GEO Core Data Set Matrix, as compiled during the first IEA/GEO Data Working Group Meeting in January 1996; it has been made available as a relational database by UNEP/GRID-Geneva. The matrix is included in the meeting report, published as a separate background report to GEO-1. In an attempt to improve access to such an overview and to promote harmonization of data use for environment assessment, a prototype of the Core Data list has been made available on Internet through URL http://info.coredata.rivm.nl.

The difference between the list of data sets of Appendix I and the Core Data Set Matrix can be used to highlight the *data gaps* for integrated environment assessment. Major data gaps exist for population, health (mortality, morbidity), agriculture (yields, land management practices), waste, land cover and traffic.

The Conventional Development scenario (CD) as applied in the first GEO has been derived from IPCC (Legget et al., 1992) and SEI (Raskin et al., 1995). This 'business-as-usual' scenario is briefly described in Chapter 2, while the major future assumptions are included in Table 2.1. More details on the CD scenario and the adaptations which had to be made for the analysis in GEO-1 are given in **Appendix II**. To address the need for alternative scenarios, the Global Scenario Group has developed several global pathways, ranging from 'Breakdown' to 'Great transition', as presented in Figure 2.1. Two variants to the Conventional Development scenario have been briefly analyzed by RIVM for several indicators on the global scale, as presented in Figure 7.3. Such scenarios will need to be further developed and - among other things - broken down geographically into smaller regions, before they can be used in quantitative and regional assessment, and forecasting as included in GEO.

The models that have been used to realize forecasting in the first GEO on the basis of core data and the CD scenario, i.e. IMAGE for global and regional environmental change, TARGETS for the global integrated assessment framework, the TARGETS Population and Health module for impacts on human health and RAINS for acidification, are briefly presented in **Appendix III**. Additional modelling work for the development of the biodiversity pressure index and the water satisfaction ratio is also included.

The UNEP/DPCSD Global Modelling Forum addresses the need for further development, harmonization and implementation of integrated and sectoral global and regional models for GEO, and similar activities related to Sustainable Development. A framework of existing models will be developed within the scope of this Forum, which because of their different resolutions in time, space and aggregation, together form a cascade of models. Models like TARGETS and Threshold 21 (Millennium Institute, USA) are used at the highest level. At a lower level of aggregation, integrated models like IMAGE, GCAM (Batelle, USA), ICAM (Carnegie-Mellon University, USA) and AIM (NIES, Japan) are used. At the lowest level of aggregation, thematic or sectoral models will be used, such as models dealing with poverty (TERI, India), land use (IIASA, Austria; CIAT, Columbia), forestry (Finnish Forest Research Institute) and river basin models (AQUA, RIVM, Netherlands). Furthermore, macro-economic models (Australian National University) and economic input-output models (GIOM model, UN) will be used to specify sectoral impacts of policy-induced changes in production and consumption patterns (DPCSD, 1996).

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APPENDIX I
Core data sets for integrated environment assessment and modelling

Following is the list of major global and regional data sets which are currently used by RIVM to enable integrated, model-based assessment and forecasting for environmental and health issues. This list is not meant to be exhaustive or prescribing, but does give an impression of the amount and type of data needed for quantitative and regional analysis of the nature presented in this report. The data needs for integrated environment assessments (IEA) in general are further elaborated in the IEA/GEO Core Data Working Group.

The data sets are grouped according to theme or data realm, including a category for very broad data sets such as the World Bank's World Data CD-ROM or WRI's World Resources database, and one for Support Information, which includes background data sets like watershed boundaries, and textual databases for literature research and policy information. The thematic grouping is not exclusive and only serves the purpose of presenting an overview of such an extensive list.

Table A.1 *Core data sets underlying this report*

Data set name	Source	Time period	Geographical coverage	Spatial resolution
Agriculture, forestry, fishery				
AGROSTAT 1992	FAO	1961-1990	world	countries
Animal stocks European Union	Eurostat	1977-1995	Europe/EU	NUTS-0/1
Crop areas European Union	Eurostat	1975-1995	Europe/EU	NUTS-0/1
FAOSTAT 1995	FAO	1961-1993	world	countries
Growing season database Europe	RIVM	1992	Europe	thematic areas, 10“ x 10”
Historical agricultural indicators (HYDE)	RIVM	1890-1990	world	countries, regions
International fertilizer statistics	IFA	1971-1994	world	countries
Time series state of food and agriculture world (SOFA'94)	FAO	1961-1993	world	countries
World fishery production (FISHSTAT-PC)	FAO	1950-1994	world	countries
Climate				
Climate database Europe	CEC	1930-1987	Pan-Europe/EU	stations
CLIMATE global database (temp., precip., evapo., cloudiness)	RIVM	1931-1960	world	0.5^o x 0.5^o
IIASA Climate Database	IIASA	1991	world	0.5^o x 0.5^o
Monthly surface air temperature and precipitation world	NCAR	1920-1980	world	0.5^o x 0.5^o
Observational Data Sets (ODS) of weather stations	ECMWF	1980-1989	world	stations
Precipitation excess Europe	RIVM	1991	Europe/EU	0.5^o x 0.5^o
Wind Vector Grids in Europe	KNMI	1983-1996	Pan-Europe	stations
Demography, health				
Demographics of the republics former Soviet Union (FirstBookDIS) 1992	New World Demographics	1950-1990	CIS	sub-national
Global Mortality Database	WHO	1950-1995	world	countries
Global population density	NASA, Harvard University, UNEP	1984, 1985	world	1^o x 1^o
Global population density and totals	NCGIA	1994	world	5“ x 5”
Gridded population data world per country	CIR/CIESIN	1971-2005	world	20“ x 30”, 5“x 7.5”

Data set name	Source	Time period	Geographical coverage	Spatial resolution
Health for all, Europe	WHO	1970-1990	Europe	countries
Health for all, global indicators	WHO	1983-1994	world	countries
Historical population indicators (HYDE)	RIVM	1890-1990	world	various
International Data Base (global demographic and socioeconomic data)	CIR	1950-2050	world	countries, provinces
Mortality for sub-national administrative units of Europe	Eurostat	1980-1990	Europe/EU	NUTS-2
OECD-CREDES Health data programme	AEA	1960-1990	OECD	countries
Population density Africa	UNEP	1991	Africa	5“ x 5”
Population density China	NGS	1987	China	sub-national
Population density Europe	RIVM	1989-1992	Pan-Europe	10“ x 10”
Sub-national boundaries and population of Latin America, US, Europe, Africa, CIS	CIAT,ESRI, Eurostat,UNEP, NWD	1971-1990	Latin America	sub-national
World cities population database WCPD	UNEP	1990	world	places
World cities populations	Bartholomew	1991	world	places
World population prospects: the 1992 revision	UN-DESIPA	1950-2025	world	countries
World population prospects: the 1994 revision	UN-DESIPA	1950-2050	world	countries
Economy				
Africa Development Indicators	World Bank	1970-1994	Africa	countries
Historical economic indicators (HYDE)	RIVM	1890-1990	world	countries, regions
Time series European Union: Eurostat-CD, Panorama of EU-Industry	Eurostat	1983-1993	Europe/EU	NUTS-2
Trade Analysis System PC-TAS	UNCTAD/ITC/ GATT	1990-1994	OECD	countries
World Debt Tables 1993-94	World Bank	1970-1993	world	countries
Environment				
Acid deposition in Europe	RIVM	1989	Europe/EU	thematic areas
Agricultural waste burning	RIVM	1991	world	1^o x 1^o
Air Quality in Major European Cities	RIVM	1985-1992	Pan-Europe	places
AIRBASE Air Pollution Information System	CEC	1968-1995	EU, Pan-Europe	stations
Aluminium concentrations in groundwater in Europe	RIVM	1990	Pan-Europe	10“ x 10”
Areas with saline seepage in the European Union	RIVM	1996	Pan-Europe	thematic areas
Biomass burning	Max Planck Institute	1975-1980	world	1^o x 1^o, 5^o x 5^o
CORINAIR	CITEPA	1985, 1990	Europe/EU	NUTS-1/2/4
Critical loads/levels in Europe	RIVM	1996	Pan-Europe	150 x 150 km
EDACS: European Deposition Maps of Acidifying Components on a Small scale	RIVM	1989, 1993	Pan-Europe	10“ x 10”
EDGAR: Emission Database for Global	RIVM	1971-1992	world	1^o x 1^o
Endangered ecosystems Europe	RIVM	1992	Pan-Europe	thematic areas, 10“x 10”
Environmental statistical database (IEDS)	UN-ECE	1980-1992	OECD	countries
Erosion database Europe	ISRIC	1992	Pan-Europe	thematic areas, 10“ x 10”
European Air Quality Maps	RIVM	1989-1990	Pan-Europe	5 0 x 50 km
Forest soil ecosystems database	SC-DLO	1992	Pan-Europe	0.5^o x 1^o
Global assessment of human induced soil degradation (GLASOD)	UNEP/ISRIC	1991	world	thematic areas
Global distribution, characteristics, methane emission natural wetlands	NCAR	1986	world	1^o x 1^o
Global Ecosystems Database	USDOC/NGDC/ EPA	1992	world	10“ x 10”
Global ecosystems database 1992, 1994	NOAA-NGDC/ ERL/ EPA	1992-1994	world	l0“ x 10”

Data set name	Source	Time period	Geographical coverage	Spatial resolution
Global environmental research data (Global Grass CD II)	US-ACE	1993	world	5“ x 5”
Global ozone data (TOMS)	NASA	1978-1991	world	1^o x 1^o
Groundwater nitrate concentration Europe	RIVM	1992	Europe	thematic areas
Groundwater resources in the EC	RIVM	1992	Europe	thematic areas
Halons and methyl chloroform production and emission data	ICI	1960-1992	world	thematic areas
Holdridge Life Zone Classification	IIASA/RIVM	1931-1960	world	0.5^o x 0.5^o
Hydrogeology Africa (RIVM)	UNDP	1994	Africa	thematic areas
Landfills in Europe	Eurostat	1991	Europe/EU	NUTS-2
LOTOS emission database 1986	TNO	1986	Pan-Europe	1^o x 2^o
Methane emission from animals	NCAR	1984	world	1^o x 1^o
NASA global distribution of aircraft emissions	NASA	1990	world	1^o x 1^o
Nitrogen excretion by various categories of animals	RIVM	1985	world	1^o x 1^o
Nitrogen loads Europe	RIVM	1991	Europe/EU	various
Nitrogen pollution in Europe	RIVM	1991	Europe/EU	thematic areas
Pesticides loads Europe in soils and groundwater	Eurostat/FAO/ RIVM	1991	Pan-Europe	countries, 10“ x 10”
Production and Emission data on CFCs and HCFCs	AFEAS	1931-1991	world	places
Protected areas Africa	UNEP	1989	Africa	thematic areas
Risk map of European nuclear powerplants	RIVM	1992	Pan-Europe	0.5^o x 1^o
Road traffic: fuel consumption and emissions	TNO	1990	world	countries
SO_2 concentrations Europe	RIVM	1992	Europe/EU	5“ x 5”
Socioeconomic impacts study environmental problems (SEIS)	RIVM	1994	India	country
Soil Organic Matter Map of Europe	RIVM	1993	Europe/EU	10“ x 10”
Soil Water Holding Capacity	NASA	1990	world	1^o x 1^o
Total Ozone Mapping Spectrometer (TOMS)	NASA	1978-1991	world	1^o x 1.25^o
Tropospheric Ozone Research (TOR)	Eurotrac/EMEP	1988-1995	Pan-Europe	stations
Wetlands Africa	ESRI	1993	Africa	thematic areas
Wetlands in the European Communities	CEC	1991	Europe/EU	thematic areas
World ecosystems (Olson)	NOAA	1970-1989	world	0.5^o x 0.5^o
World wilderness areas	UNEP	1989	world	thematic areas
WSL global distribution of aircraft emissions at 5 x 5 degree	WSL	1989-1990	world	5^o x 5^o
Industry, energy				
BP Statistical Review of World Energy	BP	1965-1993	world	countries
Energy Statistics and Energy Balances	IEA	1960-1992	OECD	countries
Historical energy/emissions indicators (HYDE)	RIVM	1890-1990	world	countries, regions
Historical industrial indicators (HYDE)	RIVM	1890-1990	world	countries, regions
IISI Steel Production and ConsumptionI Statistics	ISI	1983-1992	OECD	countries
Industrial Areas in the EU	RIVM	1992	Europe/EU	thematic areas
UN Energy Statistics and Population Database	UNSTAT	1950-1991	world	countries
UN-ECE Buildings Statistics	UN-ECE	1980-1990	world	countries
UNSO Commodity Production Statistics	Aristotle University	1970-1990	world	countries
Land cover				
Experimental calibrated global vegetation index ECGVI 1994	NOAA	1985-1991	world	10“ x 10”
Global distribution of rice paddies	RIVM	1994	world	1^o x 1^o
Global distribution of wetlands	Max Planck Institute	1988	world	2.5^o x 2.5^o
Global soils for climate research (Zobler)	NGDC		world	1^o x 1^o

Data set name	Source	Time period	Geographical coverage	Spatial resolution
Land cover(continued)				
Global vegetation database (Matthews)	NASA/GISS	1992	world	1º x 1º
Historical land cover indicators (HYDE)	RIVM	1890-1990	world	various
Monthly generalized global vegetation index	NOAA	1985-1988	world	10“ x 10”
Natural Vegetation of the European Communities	CEC	1989	Europe/EU	areas
Normalized Difference Vegetation Index (NDVI)	NOAA	1983-1984	world	1º x 1º
Pan-European 10 minutes land use database	RIVM	1975-1990	Pan-Europe	10“ x 10”
Pan-European land use statistical database	RIVM	1985-1990	Pan-Europe	various
Pan-European land use vector database	RIVM	1975-1985	Pan-Europe	thematic areas
Soil database for Europe	RIVM	1993	Europe/EU	10“ x 10”
Soil Map of the European Communities	CEC	1985	Europe/EU	thematic areas
Soil map of the world	FAO/UNESCO	1974, 1994	world	thematic areas
Vegetation map of Brazil 1988	USGS/EDC	1988	Brazil	thematic areas
Vegetation, land use and seasonal albedo	NCAR	1950-79	world	1º x 1º
World Soils for Global Climate Modelling (Zobler)	NASA	1974-1981	world	1º x 1º
Broad data sets				
Global socioeconomic indicators (World Data) 1994, 1995	World Bank	1962-1992	world	countries
Global topographic database: digital chart of the world (DCW) 1992, 1993	ESRI	1993	world	various
Human Development Report database 1994-1995 (UNDP)	RIVM	1992	world	countries
Social Indicators of Development 1993-1994	World Bank	1965-1992	world	countries
World development indicators (WDI) 1994	World Bank	1970-1992	world	countries
World resources database 1992-1993	WRI	1970-1993	world	countries
World Tables 1993, 1994	World Bank	1970-1992	world	countries
Global topographic database: ArcWorld 1: 3M 1992	ESRI	1992	world	various
Support information				
Chemical Evaluation Search And Retrieval System (CESARS)	Mich.Dep. of Nat.Resources	1983-1995	world	---
CHEMINFO	Mich.Dep. of Nat.Resources	1983-1995	world	---
Delta Study	IIASA	1950-1988	Rhine basin	catchment
Development activity information world (DAI) 1994,1996	IDRC	1930-2013	world	world
ECOTOX aquatic ecotoxicological database	RIVM	1993-1994	world	---
European emission sources	RIVM	1980-1994	Pan-Europe	0.5º x 1º
Global elevation map ETOPO-5	NOAA/NGDC	1986	world	5“ x 5”
Global relief data	NOAA/NGDC	1980-1990	world	various
Global river basins database	RIVM	1996	world	catcments
Global topographic grids	RIVM	1996	world	various
Hydrogeology Europe (RIVM)	RIVM	1993	Pan-Europe	thematic areas
Major settlements Pan-Europe	CEC/EEA	1989	Pan-Europe	places
Maps ‘n’ Facts (PC Globe). World Edition, Version 1.0	Broderbund Software	1989-1991	world	countries
Monthly river discharge of major rivers	GRDC	1996	world	stations
River basin Ganges, Bramaputra	RIVM	1994	India	catchments
River basin Rhine, Meuse	RIVM	1995	Pan-Europe	catcment
River basins Africa	UNEP	1984	Africa	catchments
River basins Europe	RIVM/Eurostat	1994	Pan-Europe	catchments
River basins world (GGHYDRO)	Trent University	1994	world	catchments, 1ºx 1º

Data set name	Source	Time period	Geographical coverage	Spatial resolution
Support information (continued)				
River basins world (Global Grass)	Rutgers University	1993	world	catchments, 5“ x 5”
RTECS - Registry of Toxic Effects of Chemical Substances	NIOSH	1983-1996	world	---
Topographic index of world places (Times World Index)	Bartholomew	1991	world	places
UNCED Earth Summit Rio de Janeiro 1992 / Agenda-21 / Treaties	IDRC	1972-1992	world	world
World boundary databank WBDII 1972	DMA/ESRI/ UNEP	1972	world	various
World boundary databank WBDII 1972 - PC version	UNEP	1993	world	various
Worldwide digital terrain data (TerrainBase)	NGDC	1994	world	various

APPENDIX II
Scenario interpretation

The scenario analyzed in this report i.e. the Conventional Development scenario, has been compiled by SEI, the Stockholm Environment Institute (Leach, 1995; Raskin et al., 1995a; Raskin et al., 1995b). The assessment required the adaptation of the supplied scenario to the models used for this analysis. The adaptations relate to regional divisions, time horizon and thematic content. There are several aspects to this.

First, some environmental phenomena had not been specified in the Conventional Development (CD) scenario. The clearest example is the emission of sulphur oxides. Emission estimations for GEO have been added on the basis of the IMAGE Baseline A scenario, which resembles the CD scenario in its assumed energy consumption per region. It introduces the necessary assumptions an fuel mix by sector, technology and location of activities.

Second, a number of assumed developments had been specified in the original CD scenario but not at the level of detail that is required to evaluate the impacts of these developments. One important sort of detail required is (much) spatial detail. This is described later in this appendix, together with the conversions between different regional breakdowns. Another example is crops. The CD scenario specifies assumed agricultural production per group of agricultural products (e.g. ‘total cereals’ or ‘meat’). In order to analyze the effects on, for example, agricultural water demand, this has been broken down further, to the level of ‘maize’ and ‘beef’. This breakdown, together with the higher spatial resolution, allowed the CD assumptions to be translated into a new landuse pattern, taking into account the distribution of population, soil quality and climate. Obviously, additional assumptions have been introduced in making the further breakdown.

Third, the original CD scenario leaves one important degree of freedom with respect to the direction of trade flows. For example, imported food assumed to be required in Asian countries could be imported from Eastern Europe or in Latin America. Therefore, before a consistent projection of environmental developments in - for example - Argentina could be made, it had to be clear how much food this country would assumedly produce for export to Asian countries. This requires additional assumptions. In the present analysis, import flows have been allocated to assumed exporting countries following, as much as possible, the vision implied by the pattern of export orientation and export capacity, as apparent from the degrees of self-sufficiency of countries in the original CD scenario.

Fourth, the integrated models used in the analysis have been set up to estimate the consequences of the scenario. This involves detailed checks on physical reality (e.g. current technologies and efficiencies, or soil quality and climate) and known correlations (e.g. diet correlated with income). Where parts of the models have been by-passed to ‘force’ the analysis in the direction of the CD scenario, potential inconsistencies are still lurking.

Main adaptations in regional divisions

As noted in Chapter 2, substantial differences exist between the regional divisions of the scenario as originally produced by SEI; the spatially explicit analysis carried out by RIVM, often using the IMAGE 2 model; and the reporting of the results for the first GEO assessment. Each of the three reflects its roots: linkage to natural or regional statistics and projections; linkage to physical reality; and linkage to UNEP’s policy audience. Extensive conversions had to be made to relate these different divisions. This is not unusual in integrated analysis, but it does introduce yet unknown inaccuracies. An overview of the regional conversions follows.

(1) Conversion in regional breakdown between scenario and analysis
(executed by SEI)

PoleStar (10 regions) *Scenario specification*	*IMAGE 2 (13 regions)* *Analysis*
North America	USA (2) and Canada (1)
Latin America	Latin America (3)
Africa	Africa (4)
West Europe (- Turkey - former Yugoslavia)	OECD Europe (5)
Eastern Europe (+ former Yugoslavia)	Eastern Europe (6)
CIS	CIS (7)
Middle East (+ Turkey)	Middle East (8)
China+ (+ Kampuchea)	China and C.P. Asia (10)
S and SE Asia	India and other S Asia (9) and East Asia (11)
OECD Pacific	Oceania (12) and Japan (13)

(2) Conversion in regional breakdown between analysis and reporting

IMAGE2 (13 regions) *Analysis*	*GEO (6 regions)* *Reporting*
USA (2) and Canada (1)	North America
Latin America (3) (-French Guyana)	Latin America
Africa (4)	Africa
OECD Europe (5) and Eastern Europe (6) and CIS (7) (+ French Guyana)	Europe and former USSR
Middle East (8) (- Afghanistan, - Iran, - Israel)	West Asia
China and C.P. Asia (10) and India and other S Asia (9) and East Asia (11) and Oceania (12) and Japan (13) (+ Afghanistan + Iran + Israel)	Asia and Pacific

Note: regional divisions at analysis and reporting levels were not adjusted for countries listed in between brackets.

Main adaptations for time frames

For GEO-1, the initial time horizon was set to the year 2015, i.e. one generation from now. A second horizon of the year 2050 has been added to look even further into the future. This also allows the incorporation of changes which may only show in several decades from now, such as the changes in population size and structure as result of the health transition and the concomitant changes in consumption and production. Some ‘system delays’ may even take longer, perhaps resulting in the need to stretch the time horizon beyond 2050. Allowing for the effects of the increase in life expectancy would need a time horizon including several generations (UN, 1992). Models like IMAGE and TARGETS can, in principle, produce forecasts up to the year 2100 and even beyond. To improve reliability of such forecasting for the distant future, the models are calibrated and validated against historical data going back to 1890 and available through HYDE, the Hundred Year Database of the Environment (Klein Goldewijk and Battjes, 1995).

The scenario as compiled by SEI contains projections for the years 1990, 2025 and 2050. Some variables are specified with five-year time steps until 2025. Where reporting of scenario assumptions for GEO was required for the year 2015, the available assumption points have been interpolated according to the trend in the original scenario. For model calculations, the original 2025 assumptions have been used as input.

Main adaptations for thematic contents

Energy related:
The energy/industry calculations made by IMAGE are by-passed after 1990. This was done to avoid too much of an impact of the model structure and model assumptions and to prevent too much attention to the remarkable differences noted in past and future energy carrier distribution. Instead, IPCC's IS92a emission figures were used after 1990 (Leggett et al., 1992). Because the IS92a scenario is used in the Conventional Development scenario for demographic and economic developments as well, it is assumed that this method causes minor changes only. The use of modern and traditional biofuels is derived from the IMAGE Baseline A scenario (Alcamo and Kreileman, 1996). The use of these biofuels is attuned to IS92A.
The Industry Value Added as a fraction of GDP is taken from SEI data.

Sulphur related:
Sulphur dioxide emissions not covered by the scenario, and required to analyze climate change and acidification, were derived from IPCC's IS92a scenario (Leggett et al., 1992). The sulphur dioxide emissions from the energy and manufacturing sector are kept constant at their 1990 levels (conforming to the IMAGE Baseline-A scenario). Here IS92A is not used because regional emission figures in 1990 differ between IMAGE and IS92A (IMAGE requires regional figures, while IS92A requires global figures).

Land related:
Food intake: The caloric intake simulation by IMAGE have been by-passed. Caloric-intake figures up to 1990 are based on IMAGE input, and scenario figures are based on the CD scenario (ratio 2025/1990 and 2050/1990). Especially in this part the trends of the conventional development scenario have been considered to be of greater importance than the absolute figures.

Suitable Land: The CD scenario prescribes the necessary suitable land area. For the analysis this has been interpreted, using the IMAGE model, considering the quality of land (climate, soil quality, water availability). The difference can partly be attributed to the concept of land use (IMAGE) vs. land cover (scenario).

- The fraction for 'other use of crops' is taken from the CD scenario by using the definition: Fraction other use of crops = Other & Losses / Total Supply.
- The fraction for 'other use of animal products' is taken from the CD scenario by using the definition:
  Fraction other use of animal products = (Other & Losses + Animal Feed) / Total Supply.
- The change in the management factor for crops that are used for consumption is taken from the CD scenario by using the definition:
  Change in management factor = Change in Farm Unit per harvest / Change in Cropping intensity.
  This change is used insofar as the maximum level of the management factor used in Baseline A is not exceeded. In the case of exceedence, the maximum level of Baseline A is used.
- The change in the fraction harvested area is taken from the CD scenario by using the change in cropping intensity averaged over all crops.
  The following desired levels of self-sufficiency are used for the trade of biofuels:

- Maize as biofuel: All regions: 1.00 (no trade).
- Sugar as biofuel, woody biofuels and non-woody biofuels: Eastern Europe, CIS and Middle East: 1.00 (no trade); Latin America: 15.00 (export); Africa: 1.25 (export); Canada, USA, OECD Europe, India+, China+, East Asia and Oceania: 0.50 (import); Japan: 0.00 (import).

- The following desired levels of self-sufficiency (DSSR) are used for the trade of food products:
  - Meat:
    Canada, USA, Latin America, OECD Europe, CIS and Oceania: DSSR2050 = SSR1990+0.1; China+: DSSR2050 = SSR1990-0.05; Africa, Eastern Europe, Middle East, India+, East Asia and Japan: DSSR2050 = SSR1990.
  - Milk:
    Canada, USA, OECD Europe, CIS and Oceania: DSSR2050 = SSR1990+0.2; Latin America: DSSR2050 = SSR1990+0.1; Africa, Eastern Europe, Middle East, India+, China+, East Asia and Japan: DSSR2050 = SSR1990.
  - Temperate cereals:
    Canada, USA, OECD Europe, Eastern Europe and CIS: DSSR2050 = SSR1990+0.5; Latin America: DSSR2050 = SSR1990+0.2; Oceania: DSSR2050 = SSR1990-2.5; Africa, Middle East, India+, China+, East Asia and Japan: DSSR2050 = SSR1990.
  - Maize:
    Canada, USA, OECD Europe, Eastern Europe and CIS: DSSR2050 = SSR1990+0.5; Latin America: DSSR2050 = SSR1990+0.2; Africa, Middle East, India+, China+, East Asia, Oceania and Japan: DSSR2050 = SSR1990.
  - Oil crops:
    CIS and Oceania: DSSR2050 = SSR1990+0.5; OECD Europe and Eastern Europe: DSSR2050 = SSR1990+0.2; Canada, USA, Latin America, Africa, Middle East, India+, China+, East Asia and Japan: DSSR2050 = SSR1990.

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APPENDIX III
Model descriptions

A. The IMAGE 2 model

The IMAGE 2 model (Alcamo, 1994) is a multi-disciplinary, integrated model designed to simulate the dynamics of the global society-biosphere-climate system. The objectives of the model are to investigate linkages and feedbacks in the system and to evaluate the consequences of climate-related policies. Dynamic calculations are performed from 1970 to 2100, with a spatial scale ranging from grid (0.5º x 0.5º latitude-longitude) to world regional level, depending on the submodel.

The model consists of three fully linked subsystems: Energy-Industry, Terrestrial Environment, and Atmosphere-Ocean. The Energy-Industry models compute the emissions of greenhouse gases in 13 world regions as a function of energy consumption and industrial production. End-use energy consumption is computed using various economic/demographic driving forces. The Terrestrial Environment models simulate changes in global land cover on a grid scale based on climatic and economic factors, as well as on the flux of CO_2 and other greenhouse gases between the biosphere and atmosphere. The Atmosphere-Ocean models compute the build-up of greenhouse gases in the atmosphere and the resulting zonal-average temperature and precipitation patterns.

The fully linked model has been tested against data from 1970 to 1990. After calibration it can reproduce the following observed relationships: regional energy consumption and energy-related emissions, terrestrial flux of carbon dioxide and emissions of greenhouse gases, and

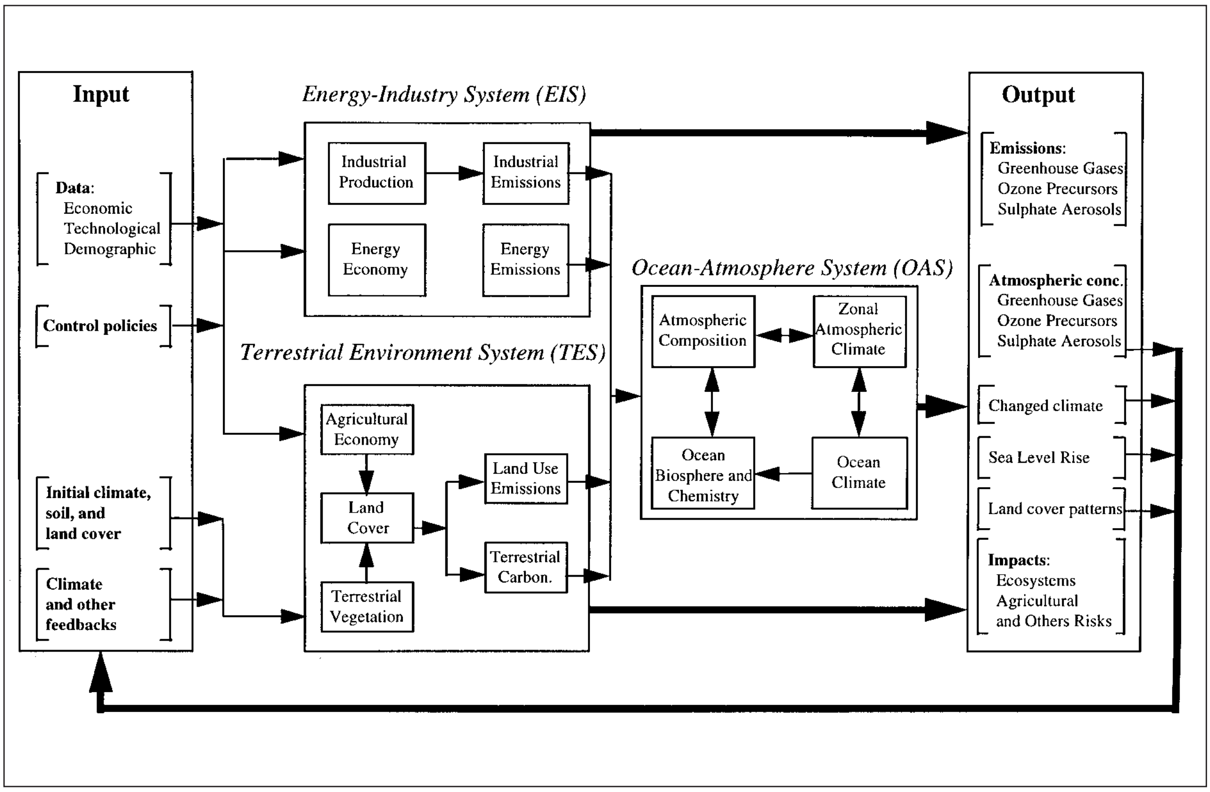

Figure A.2. *A schematic overview of IMAGE 2*
Source: Alcamo and Kreileman (1996).

concentrations of greenhouse gases in the atmosphere and transformation of land cover. The model can also simulate current zonal average surface and vertical temperatures.

The IMAGE 2 model is primarily designed to address global climate-change issues and thus support climate-related policy-making. Due to its integrated character and policy-oriented model structure, the IMAGE 2 model is used to support studies that contribute to the chapter on integrated model-based environmental forecasting in the Global Environment Outlook. IMAGE 2 contributes to: 1) the chapter on interactions between the atmosphere, land and water, 2) a geographically explicit study on future land cover and land use (part of the model) and 3) the development of a global biodiversity indicator (via post-processing of model data sets: N.B. not a integrated part of the model). A land degradation model is currently under development, as well as a model that explicitly captures trends in irrigation.

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B. The TARGETS 1.0 model

TARGETS is an integrated assessment model for global change and sustainable development using a systems approach to represent the anthropogenic disturbance of the biosphere on a global scale through a set of interrelated cause-effect chains.

A global integrated assessment model TARGETS, the acronym for Tool to Assess Regional and Global Environmental and health Targets for Sustainability, is currently being developed within RIVM's research project 'Global Dynamics and Sustainable Development'. The main objective of the project is to operationalize the concepts of global change and sustainable development. The TARGETS model is intended to provide insight into the complex interrelations between demographic, social and economic processes, and biophysical processes and effects on humans and the environment. The time horizon for the TARGETS model spans about two centuries, starting in the year 1900 and going to 2100, with time steps varying from one month to a year. The systems approach concentrates on the interactions and feedback mechanisms between the different subsystems of cause—effect chains of global change, rather than on each subsystem in isolation. The TARGETS model is being used to explore strategies for sustainable development; it is also meant to serve as a communication platform between exponents of natural and social sciences, and between scientists and policy-makers.

The TARGETS 1.0 version contains five submodels: population and health, energy, water (AQUA), land, soil and food (TERRA), and biochemical element cycles (CYCLES). Each of the submodels is calibrated for the world for the period 1900-1990. They have been reviewed externally in the course of 1996, with the first results of both the submodels and the integrated model experiments to be published in 1997. Regional implementation to allow integration with the IMAGE 2 model has been started for some of the submodels.

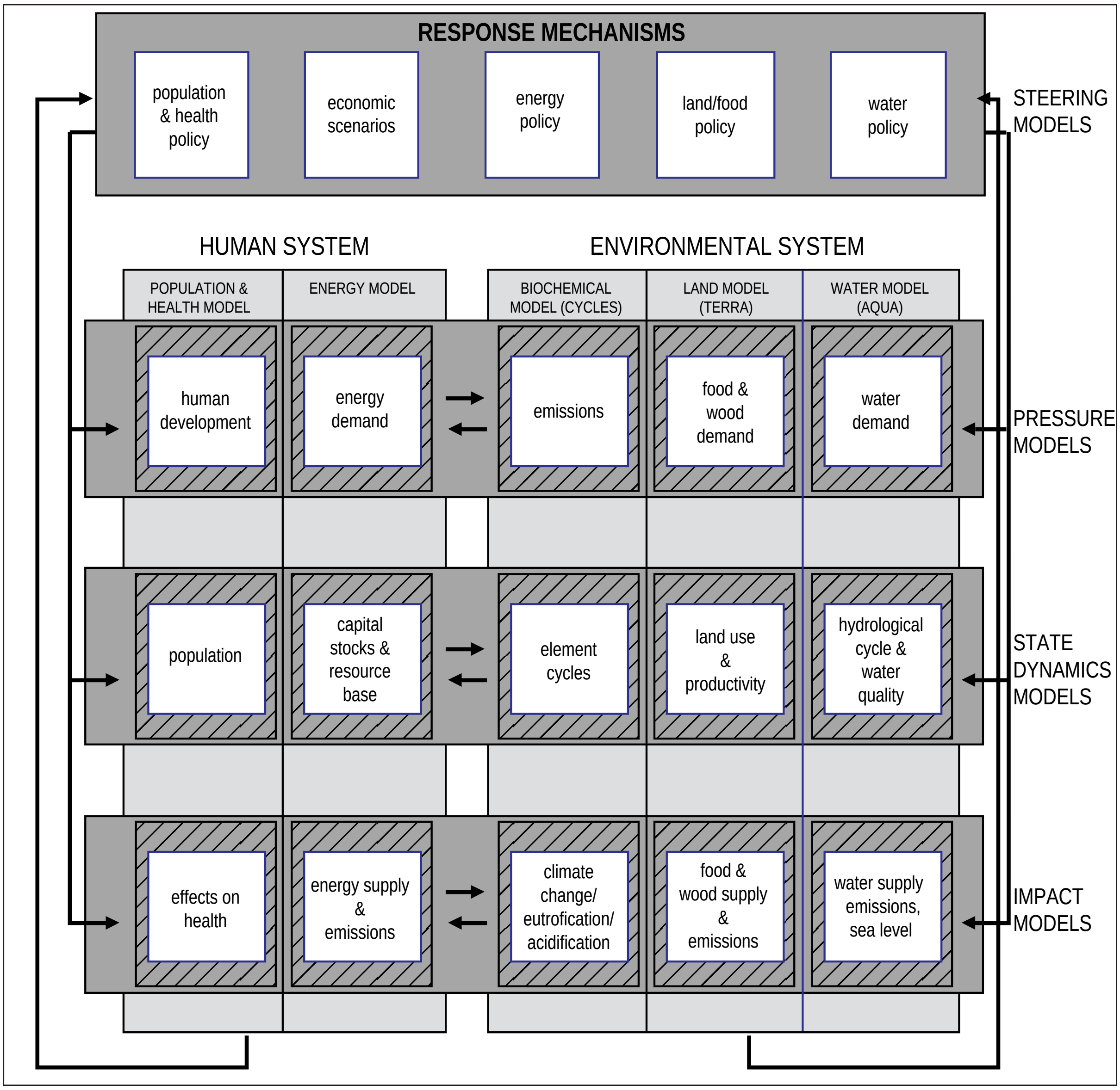

Figure A.3. *A conceptual representation of the modular perspective of TARGETS, version 1.0*
Source: Rotmans and de Vries (1997).

Reference:

Rotmans, J. and H.J.M. de Vries (eds.) (1997, forthcoming). Perspectives on global futures: the TARGETS approach. Cambridge University Press. Cambridge.

More information on the TARGETS model can be found in Rotmans and de Vries (1997, forthcoming)or can be obtained by email: globo@rivm.nl.

C. The TARGETS Population and Health model

The objective of the population and health (sub)model is to describe the long-term changes of populations in their size and structure as well as the associated changes in health under varying socioeconomic and environmental conditions in the past and future. This includes populations living in pre-industrial societies as well as those living at the highest known health levels. In our view, such a long-term public health approach should consider the main input-output relationships between population, fertility and health in terms of both environmental and societal resources. The modelling framework can be used to explore and test policy issues and to test specific hypotheses in the field. The model has been applied at the national level for China (Zeng Yi et al., 1996), India (Hutter et al., 1996), and the Netherlands and Mexico (Niessen and Hilderink, 1996).

The Population and Health module is one of the five submodels within TARGETS (see Figure A.4). The input from the other modules are per capita food intake from TERRA, the fraction of the population without access to safe drinking water from AQUA and other environmental factors (temperature increase and UV-B radiation) from CYCLES. The Gross World Product (GWP) and the availability of health services is imported from the Economics scenario generator.

The framework of the Population and Health module in TARGETS is based on the following elements within the PSIR framework, as illustrated inFigure A.5 on the next page:

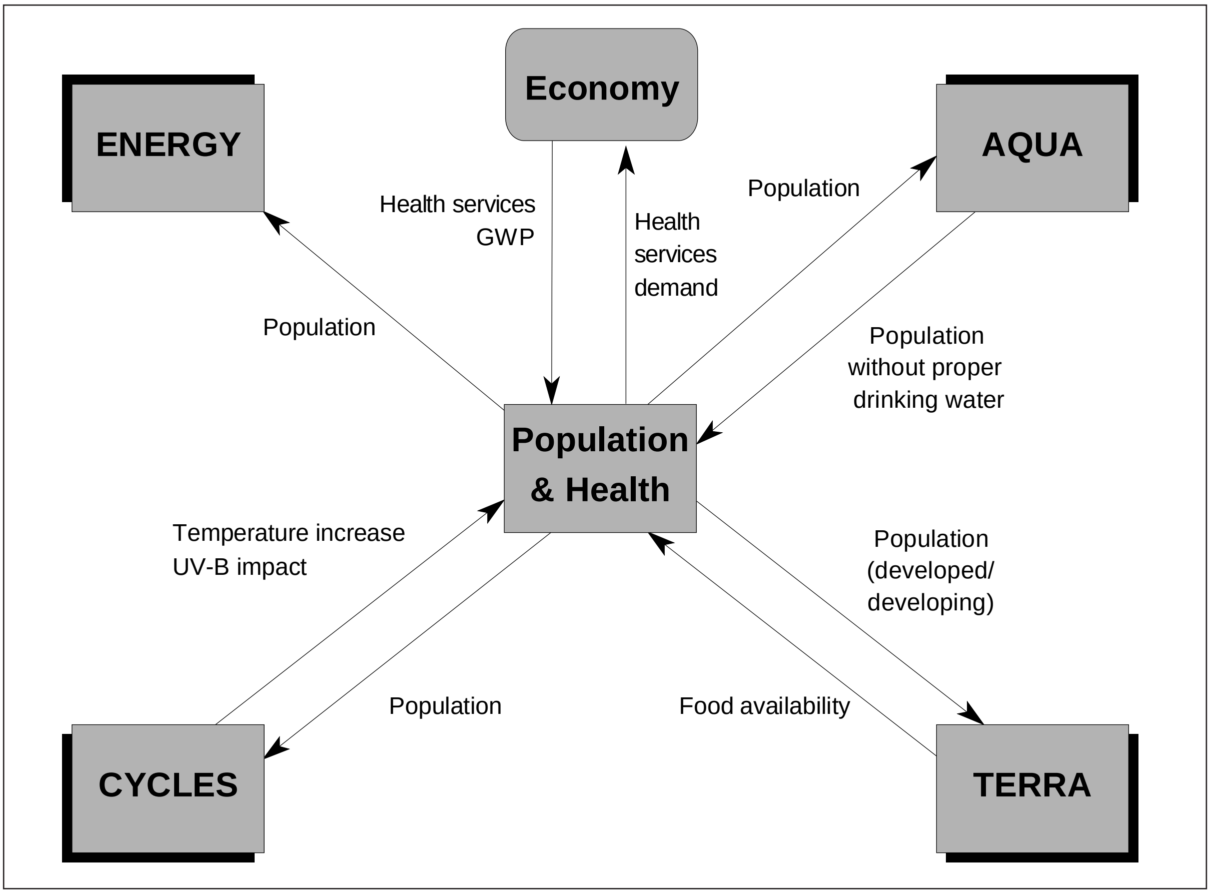

Figure A.4. *Linkages of the population and health model with the other TARGETS submodels*
Source: Niessen and Hilderink (1996).

1. A pressure component describing the health determinants, divided into socio-economic factors i.e. Gross World Product (GWP) and literacy status, and environmental factors e.g. food and water availability;
2. A state dynamics subsystem simulating the fertility behaviour and the population dynamics for disease and disease-specific mortality, both having their inputs to a population module distinguishing sex and age groups;
3. An impact subsystem that describes the quantitative and qualitative aspects of the state subsystem like the burden of disease and life expectancy, as well as the size and structure of the population;
4. A response subsystem consisting of population policies influencing the fertility behaviour, and social and health policies influencing the disease processes.

The pressures represent those factors that influence the proximate fertility determinants and the determinants of health as modelled. The selection of determinant categories is based on the

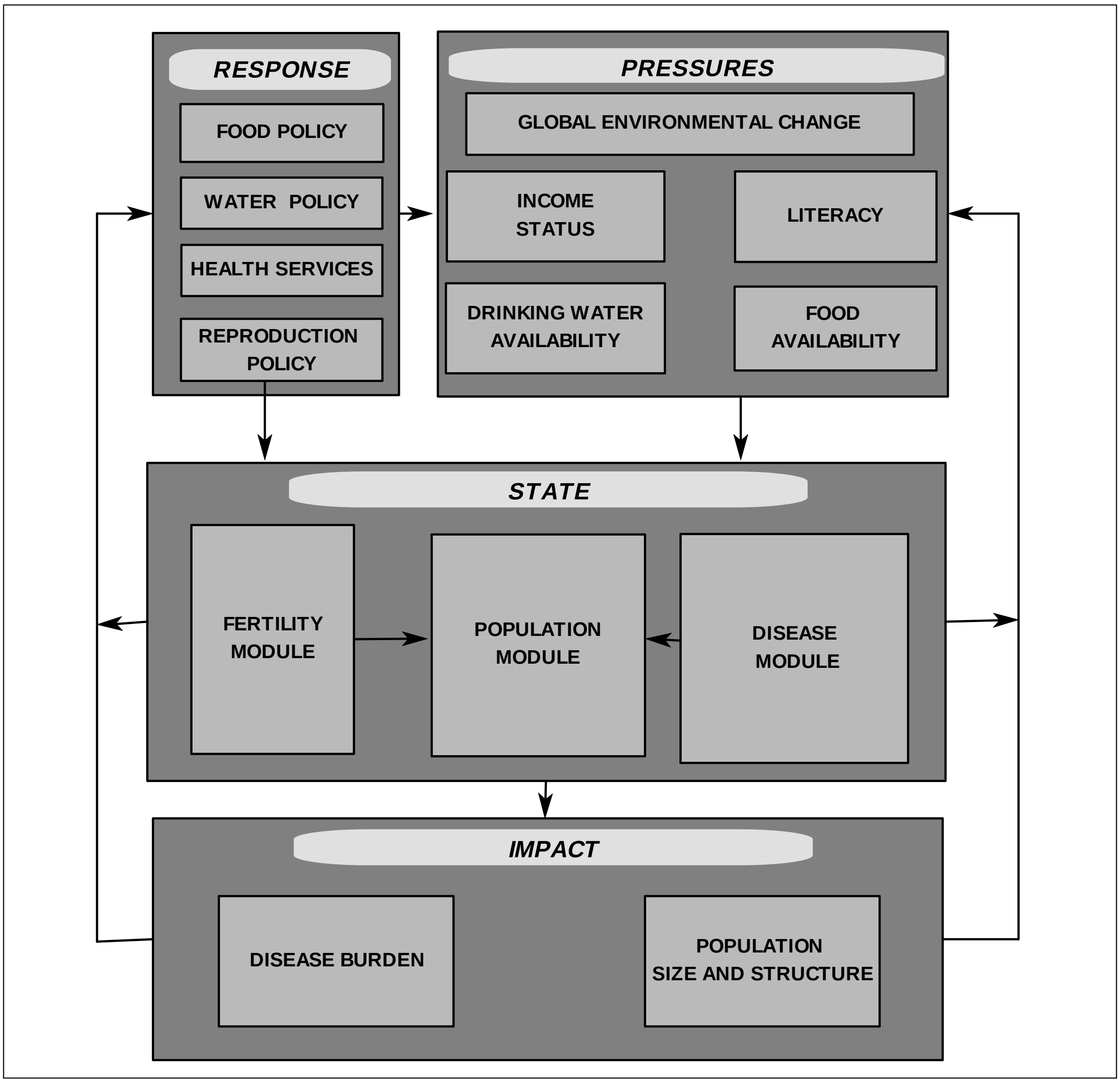

Figure A.5. *A pressure-state-impact-response representation of the TARGETS population and health module*
Source: Niessen and Hilderink (1996).

evidence on their supposed quantitative importance throughout the health transition, as reported in the literature. They are categorized in two groups: socio-economic and environmental factors. The two variables which describe the socio-economic pressures are:

1. Gross World Product (GWP) expressed in US dollars (1990). This parameter determines the available income per capita and the available resources for health services. Separate projections for the low-income countries are used in a distribution function to estimate the number of people below the absolute poverty line (World Bank, 1993)
2. The female literacy level expressed as the fraction of the adult female literate population. This parameter is computed as a delayed function of the GWP and the human development index (see below).

The variables describing the environmental pressures are:

1. Food availability (food per capita) expressed in kilocalories daily intake (from the TERRA submodel). From these projections the fraction of the population suffering from malnutrition is calculated for the subpopulations that fall under the low socio-economic status categories (see below). These are based on empirical distribution functions.
2. Drinking water and sanitation defined as the fraction of the population with proper access to safe drinking water and sanitation facilities (from the AQUA submodel) that falls under the low socioeconomic status categories. In the case of large discrepancies between the two parameters, the safe drinking-water coverage is chosen, as this factor is the most relevant of the two (Esrey, 1985; Esrey, 1991).
3. Temperature increase (from the CYCLES submodel) influencing the number of people exposed to malaria risks and the spreading of schistosomiasis, as well as those affected by heat stress, affecting cardiovascular disease mortality.

More information on the TARGETS model and sub-models can be found in Rotmans and de Vries (1997) or through contacting by email: globo@rivm.nl.

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D. The RAINS model

The Regional Acidification INformation and Simulation (RAINS) model, developed, updated and maintained at the International Institute of Applied Systems Analysis in Austria since 1982, is the first integrated environmental assessment model which has successfully been used to assist European policy on the further reduction of sulphur dioxide and nitrogen oxide emissions in the framework of the Convention on Long-Range Transboundary Air Pollution (UN/ECE). For Asia, RAINS has been developed from scratch to reflect Asian conditions, while maintaining the philosophy of linked subsystems.

The subsystems that have been modelled and linked in RAINS are (1) energy supply, (2) emissions of sulphur dioxide and nitrogen oxide (3) costs of add-on abatement technology, (4) atmospheric transport and (5) ecosystem impact using critical loads and levels.

The most important inputs for each of the modules are (1) national energy-use statistics and energy plans, (2) fuel characteristics (3) marginal and total yearly investment, maintenance and operational costs of 'reasonable available control technologies as well as best available control technologies', (4) source-receptor relationships reflecting complex (verified) models of atmospheric trajectories of air pollutants and (5) soil and ecosytem characteristics modelled to reflect the required balance (at critical loads) between acidifying and buffering chemical soil processes. These include experimental knowledge on acceptable air pollution concentration exposure (critical levels).

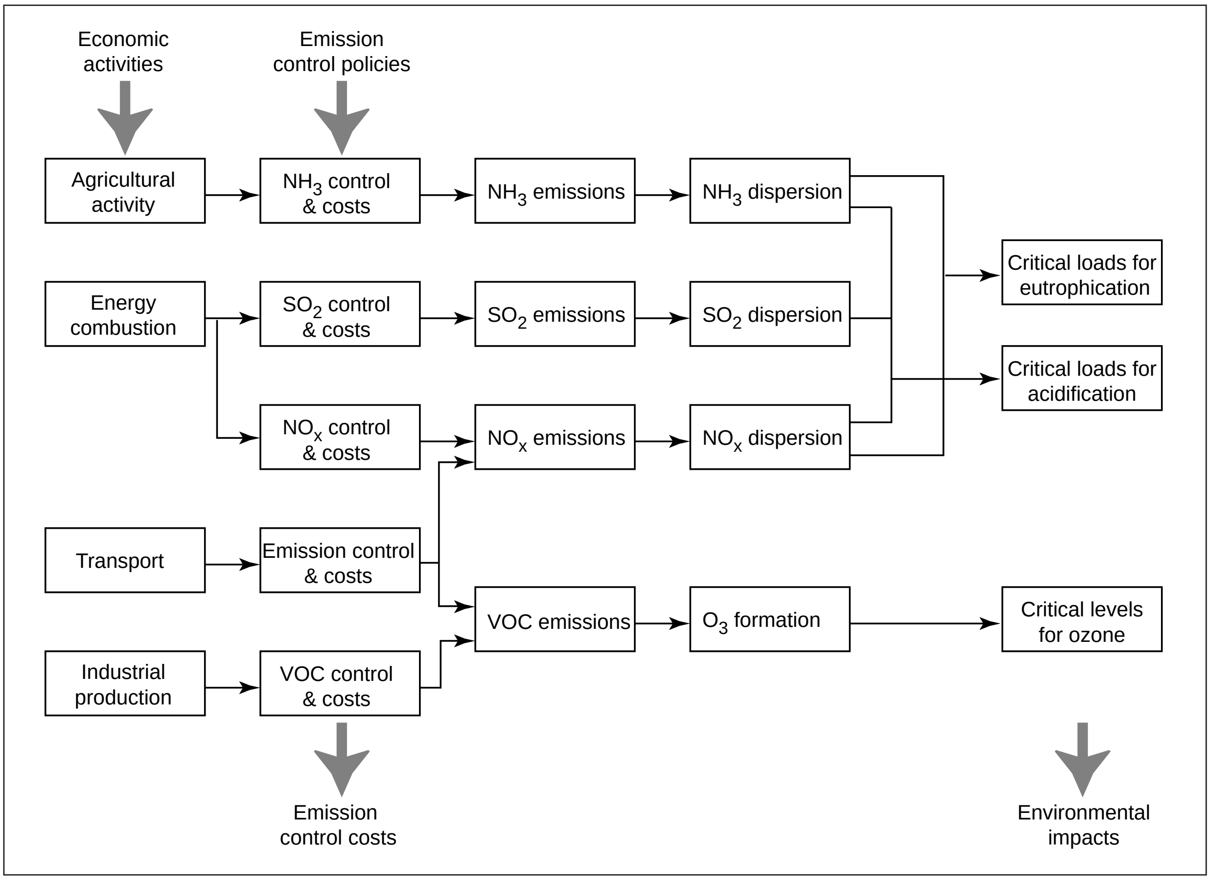

Figure A.6. *A schematic overview of RAINS*
Source: IIASA (1996).

RAINS can be run in a *forward mode*, and in a *backward mode*. In the forward mode answers are provided to questions such as 'What impacts and costs are related to a particular emission reduction strategy ?' In the backward mode a policy analyst assesses, for example, 'How can the cost of emission reductions be minimized subject to particular ecosystem protection levels ?' Many variations to these questions can be handled by means of the RAINS-Europe and RAINS-Asia models. RAINS, highly interactive and user-friendly, is operational on current personal computers.
The model was developed at the International Institute for Applied System Analysis (IIASA) in Laxenburg, Austria. More information on the RAINS model can be found in Amman (1995) or through contacting M. Amman by email: amman@iiasa.ac.at.

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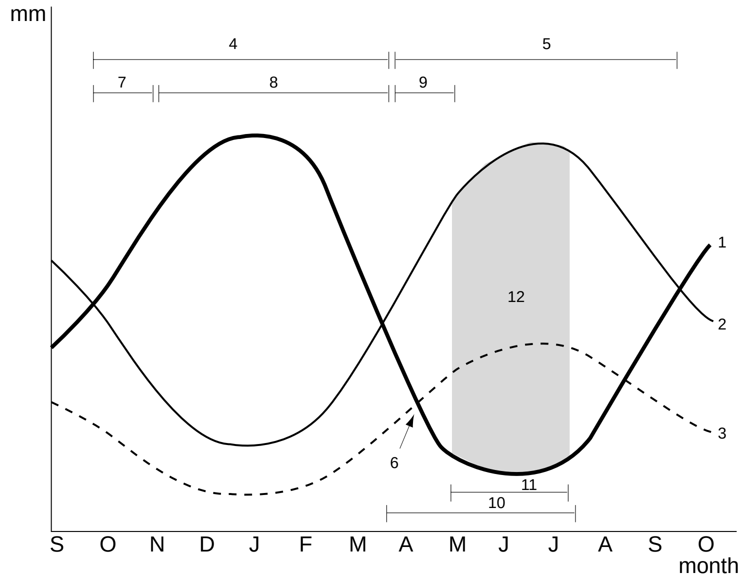
E. The water demand satisfaction model

The water demand satisfaction model for calculating the satisfaction rate of water demand on a river-basin level, is developed for applications on regional and global scales. The model is based on physical processes and a geographic explicit approach according to Klepper et al. (1995). The quantitative sectoral water demands accounted for are domestic, industrial and agricultural (Klepper et al., 1996).

Water *availability* was calculated on a 0.5 x 0.5 degree grid on a monthly basis. Precipitation and potential evapotranspiration was based on Leemans and Cramer (1991). The calculation of actual evaporation depends on vegetation and soil type as described by Conway et al. (1995) and Prentice et al. (1993). Vegetation data was taken from the IMAGE database (Zuidema et al., 1994) and soils data from FAO/UNESCO (1974). The model distributes discharge (precipitation minus evapotranspiration) from each grid cell over groundwater recharge and surface runoff as described by Klepper et al. (1995). A geological map of the world (based on Berdeke and Wunderlich (1968) was provided in electronic form by Wolters-Noordhoff. This map was converted to a map of aquifer types using the maps of Africa (UN, 1988) and Europe (IHA, 1974-1990) for calibration. Climatic variability was estimated using the map provided by Riehl (1979).

Water *demand* was calculated by adding domestic, industrial (assumed to be independent of season) and irrigation (seasonally dependent) demand. National data on per capita use, mainly based on Gleick (1993) and WRI (1992) were combined with population density (Tobler et al., 1995) to obtain a world map of domestic use. National data on industrial consumption - mainly based on Gleick (1993), with additional estimates based on the EDGAR database (Olivier et al., 1995) - were converted to maps assuming industrial activity to be proportional to urban population density, as estimated using the method described by Klepper et al. (1995). Agricultural water use was estimated by calculating crop requirements as described by Prentice et al. (1993) and Leemans and Van den Born (1994), with a map of irrigated areas based on FAO (1990) statistics using the method by Klepper et al. (1995). See also figure A.7. Return flows for the three sectors were calculated using efficiencies estimated per IMAGE region.



Legend

1 = Precipitation
2 = Potential evapotranspiration
3 = 0.5 potential evapotranspiration
4 = Precipitation > evapotranspiration (discharge to soil, groundwater and runoff)
5 = Precipitation < evapotranspiration (almost no recharge to groundwater, water is taken up by crops)
6 = Precipitation equals 0.5 potential evapotranspiration; start of growing season
7 = Building up soil moisture
8 = Stabilization soil moisture levels; surplus goes to groundwater
9 = Decrease in soil moisture
10 = Growing season
11 = Irrigation period
12 = Estimated demand for irrigation water

Note:
- the example in this figure applies to temperate climate on the Nothern hemisphere
- the modelled water demand of crops is based on theoretical crop requirements
- in case the simulated total water water demand were not in agreement with withdrawal statistics (Raskin *et al.*1995), the difference is included as additional demand. It is suggested that the differences, which are high in some cases, are due to differences in irrigation management.

Figure A.7. *Estimation of agricultural water demand*

To avoid underestimation (if any) of agricultural water withdrawals in temperate zones relative to current and projected withdrawals (Raskin *et al*. (1995) with reference to WRI (1994)), regional and subregional withdrawals in excess of what had been estimated for water-limited agricultural practices were also taken into account. These extra withdrawals have been allocated to the country's river basins in proportion to the water demand estimated for water-limited agriculture, following Klepper, *et al*. (1996).

Water demand satisfaction is the ratio of the yearly sum of water availability to total water demand. It was calculated on a river basin level, taking into account the flows from one sub-basin to a downstream basin and the distribution of supply and demand within a sub-basin, as described by Klepper et al. (1995). The global map of catchment areas (1165 in total) was mainly derived from the watershed basin's data layer on the Global GRASS CD-ROM II (CERL and Rutgers-University, 1993). Although satisfaction is computed relative to gross demand, only actual consumption is subtracted to calculate downstream supply.
For this study a preliminary version of the water demand satisfaction model was used.[1] The following preliminary classification is applied to present the satisfaction results: 'no water problems' (rates higher or equal to 1), 'few to moderate problems' (rates ranging from 0.6 to 1)

[1] The Water Satisfaction Model will be subject to external review.

and ‘moderately severe to severe’ (rates less than 0.6). The class ‘non-applicable’ covers catchments with very low population densities. These catchments (47% of the world’s land area, with 5% of the world population) have been included in the calculations, but excluded from the results.

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F. The pressure index for non-domesticated areas

The pressures on non-domesticated areas considered are: i) 'climate change', ii) 'population density', iii) 'consumption and production rate' and iv) 'forest clearance for timber'. These pressures are determined for each non-domesticated grid cell of 0.5 degrees longitude times 0.5 degrees latitude (the IMAGE grid). The pressures for each cell have been rated on a linear scale from pressure class 0 (no pressure) to pressure class 10 (very high pressure). Class 10 means a high chance of extremely poor biodiversity compared with the original state. Higher pressure values are rated as pressure class 10 to avoid an over-pessimistic result. This is a preliminary classification system, set up for the GEO.
The following linear functions were used.

i) Climate change: the pressure is rated on a scale ranging from no change in mean temperature to 2 degrees within a 20-year period.
An increase in mean temperature of 0.2 degrees in 20 years is rated as pressure class 1; an increase of 2.0 degrees in 20 years as pressure class 10. The maximum value for temperature rate of change is set at ten times the preliminary 'threshold at which ecosystems might be able to adapt effectively to climate change' (Jäger, 1987; 1990). This is based on the still rudimentary understanding of the vulnerability of ecosystems to historical temperature changes. Moreover, the maximum value of 2.0 ºC per two decades is high in comparison to the 'maximum temperature increase of 2.0 degrees'. This has been suggested as the 'absolute limit beyond which the risks of grave damage to ecosystems, and of non-linear responses, are expected to increase rapidly' (Jäger, 1990).

ii) Population density: the pressure is rated on a scale ranging from 0 to 100 persons per square kilometer.
The maximum pressure values for population density are derived from Hannah et al. (1994). Harrison (1992) and Terborch (1989) have mentioned similar levels.

iii) Consumption and production rate is characterized by GNP on a scale from US$ 0 to US$ 6,000,000 per square kilometre per year. GNP is used as an approximation of the production and consumption rate and the related use of, and pressure on, non-domesticated areas by factors such as emissions, extraction of natural resources, physical disturbances and fragmentation. The maximum GNP per square kilometre is similar to values found in highly populated and highly industrialized areas such as the lower trajectory of the Rhine.

iv) Forest clearance for timber: the pressure is rated according to the time since the most recent logging, ranging from 100 to 0 years ago. The maximum pressure value for forest clearance for timber is set at 0 years ago (class 10), assuming total ecosystem destruction; the minimum value at 100 years (class 0), assuming no pressure and total regeneration of the forest ecosystem after 100 years. Generally, a longer period for forest regeneration is assumed. For example, 'old growth forest' is generally defined as more than 200 years (Dudley, 1992).

The four pressures ratings for the remaining non-domesticated area are simply added per grid cell, resulting in a 'total pressure'. This preliminary pressure index will have to be further elaborated and underpinned in the future. For specific information, contact: ben.ten.brink@rivm.nl.

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ABOUT RIVM

RIVM, the National Institute of Public Health and the Environment in Bilthoven, The Netherlands, is a supporting scientific organization for the ministries in the Netherlands who deal with public health and the environment. Since the late 1980s, a core task of RIVM has been integrated assessment in environment and public health, on the basis of extensive monitoring, modelling, scenario analysis and an active dialogue with the scientific community and those using the assessments in policy making. RIVM fulfills specific roles in its relations with the various international organizations. To UNEP, for instance, RIVM has been a Collaborating Centre for Environment Assessment, Reporting and Forecasting since 1994.